THE UNIVERSITY OF WARWICK

PX 381: Astrophysics From Space

Jörn Wilms

Autumn 2006

email: j.wilms@warwick.ac.uk
Office: PS006

http://pulsar.astro.warwick.ac.uk/wilms/teach/astrospace
http://astro.uni-tuebingen.de/~wilms/teach/astrospace

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Aims and Objectives

Aims:
To introduce the most important physical processes and detection methods required for understanding the broad band emission spectra of astrophysical objects from the radio regime to X-rays and gamma-rays, to provide a basis for further studies in observational astrophysics.

Objectives:
At the end of this module you should be:

- able to identify the major emission mechanisms of astrophysical objects
- understand the physical basis of detection methods for UV-radiation and X-rays from astrophysical sources.
- understand how electromagnetic theory and quantum mechanics are used to predict the emission of radiation.
- able to quantify physical conditions in a variety of astrophysical systems using measured data.

Syllabus:

- Motivation for making space measurements: Absorption of IR, UV and X-rays in the Earth's atmosphere.
- Observational basis: broad-band emission spectra of compact objects in the Galaxy and Active Galactic Nuclei (AGN).
- Detection methods: physical principles of imaging and energy dispersive detectors for IR, optical, X-ray and gamma-ray radiation.
- Review of major physical processes responsible for radiation from astrophysical black holes, neutron stars and white dwarfs:
  - Black black body radiation
  - Plasma emission line spectra
  - Review of major results of atomic structure
  - Selection rules, radiative transitions
  - Radiation from free electrons, Larmor formula.
- Application of these concepts to topics selected from:
  - Bremsstrahlung
  - Synchrotron radiation
  - Comptonization

– Cyclotron radiation.

As the emphasis of the module is not on the detailed theory but to give an overview of the major results of the theory of radiation processes as applied to astrophysical observations, these physical processes will be illustrated with with topics selected from the following:

- Principles of the measurement of the temperature and density of gases irradiated by astrophysical objects.
- Measurement of the properties of jets from supermassive black holes.
- Observational determination of the physical conditions close to compact objects.

Commitment: 15 Lectures

Assessment: 1.5 hour examination

Recommended Texts:

1. H. Bradt, 2003, Astronomy Methods: A Physical Approach to Astronomical Observations, Cambridge University Press, QB 43.B7
2. T. Padmanabhan, 2000, Theoretical Astrophysics, Vol. 1: Astrophysical Processes, Cambridge University Press, QB 461.P2 Vol. 1

The lecture notes available at `http://pulsar.warwick.ac.uk/wilms/teach/radproc` or `http://astro.uni-tuebingen.de/~wilms/teach/radproc` will also be useful.

Outline

Introduction

27 Sep	Introduction, History
28 Sep	Broadband observations of astronomical objects
30 Sep	Accretion

Detectors

4 Oct	Charge Coupled Devices
5 Oct	X-ray detectors

Radiation Processes: Continuum

7 Oct	Black Body Radiation
11 Oct	Larmor's Formula
12 Oct	Synchrotron Radiation
14 Oct	*Application:* Jets, Neutron Stars
18 Oct	Comptonization
19 Oct	*Application:* Active Galaxies and Black Hole Binaries

Radiation Processes: Lines

21 Oct	Review of Atomic Structure
25 Oct	Density and Temperature Diagnostics
26/28 Oct	*Application:* Active Galaxies and Interstellar Medium

Recommended Textbooks

BRADT, H., 2003, Astronomy Methods: A Physical Approach to Astronomical Observations, Cambridge: Cambridge Univ. Press, £33

Summary of many technical details that are useful to know if you want to become a professional astronomer. Detectors, radiation processes, etc.

PADMANABHAN, T., 2000, Theoretical Astrophysics: Volume 1: Astrophysical Processes, Cambridge: Cambridge Univ. Press, £28

New introduction to the (theoretical) physics of astrophysics. Short, concise, great. Graduate level, but understandable, although not for the faint hearted...

CHARLES, P.A. & SEWARD, F.D., 1995, Exploring the X-Ray Universe, Cambridge: Cambridge Univ. Press

Introduction to X-ray astronomy, well written. Unfortunately the observational results are very much out of date by now and mainly summarise the field at the end of the 1980s.

Other Textbooks

LONGAIR, M.S., 1992, *High Energy Astrophysics, Vol. 1: Particles, Photons, and their Detection*, Cambridge: Cambridge Univ. Press, £30

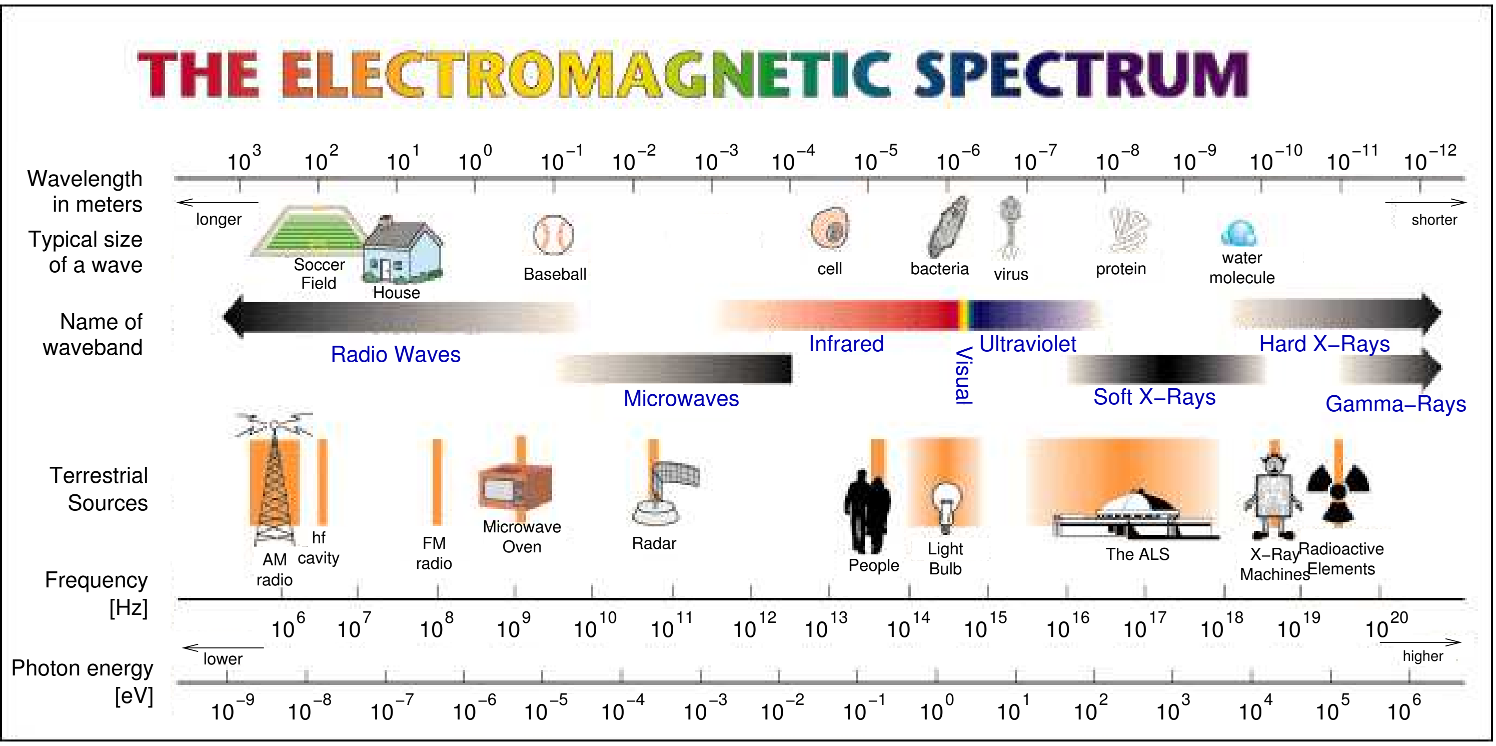
Good introduction to high energy astrophysics, the 1st volume deals extensively with high energy processes. Recommended. Everything is in SI units!

RYBICKI, G.B. & LIGHTMAN, A.P., 1979, *Radiative Processes in Astrophysics*, New York: Wiley, £59

A “must buy” for those who want to be professional astronomers, although now very expensive (I got it for $50 [£28] 10 years ago). Standard text of the field, in some areas getting outdated.

COWLEY, C.R., 1995, An Introduction to Cosmochemistry, Cambridge: Cambridge Univ. Press, £25

Beautiful and practical summary of atomic and molecular processes.



Electromagnetic Spectrum, II

As we all know, light can be characterized by

Wavelength: λ, measured in m, mm, cm, nm, Å.

Frequency: ν, measured in Hz, MHz.

Energy: E, measured in J, erg, Rydbergs, eV, keV, MeV, GeV.

Temperature: T, measured in K.

These quantities are related:

$$\lambda\nu = c \qquad E = h\nu \qquad T = E/k \tag{1.1}$$

where

$$c = 299792458\,\mathrm{m\,s^{-1}} \tag{1.2}$$

$$h = 6.6260693(11) \times 10^{-34}\,\mathrm{J\,s} \tag{1.3}$$

$$k = 1.3806505(24) \times 10^{-23}\,\mathrm{J\,K^{-1}} \tag{1.4}$$

Constants are 2002 CODATA values, `http://physics.nist.gov/cuu/Constants/index.html`
uncertainty is 1σ in units of last digit shown.

Conversion table (courtesy Eureka Scientific, `www.eurekasci.com`):

From ⇓ To ⟹	λ[Å]	$\lambda[\mu$m]	λ[cm]	ν[Hz]	E[keV]	E[erg]
λ[Å]	1	$10^{-4}\lambda$	$10^{-8}\lambda$	$3\times10^{18}/\lambda$	$12.4/\lambda$	$2\times10^{-8}/\lambda$
$\lambda[\mu$m]	$10^{4}\lambda$	1	$10^{-4}\lambda$	$3\times10^{14}/\lambda$	$1.24\times10^{-3}/\lambda$	$2\times10^{-12}/\lambda$
λ[cm]	$10^{8}\lambda$	$10^{4}\lambda$	1	$3\times10^{10}/\lambda$	$1.24\times10^{-7}/\lambda$	$2\times10^{-16}/\lambda$
ν[Hz]	$3\times10^{18}/\nu$	$3\times10^{14}/\nu$	$3\times10^{10}/\nu$	1	$4.14\times10^{-18}\nu$	$6.63\times10^{-27}\nu$
E[keV]	$12.4/E$	$1.24\times10^{-3}/E$	$1.24\times10^{-7}/E$	$2.42\times10^{17}E$	1	$1.60\times10^{-9}E$
E[erg]	$2\times10^{-8}/E$	$2\times10^{-12}/E$	$2\times10^{-16}/E$	$1.51\times10^{26}E$	$6.24\times10^{8}E$	1

Eye, I

(Aveni, 1993, p. 58)

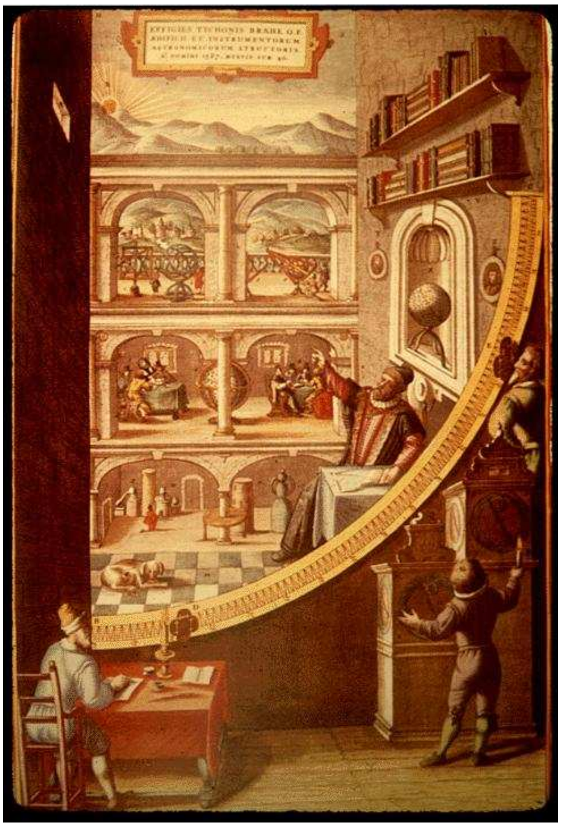
Ptolemy (∼140AD):

Syntaxis (aka Almagest):

First star catalogue

⟹ optical scientific astronomy starts around 100 AD

Eye, II

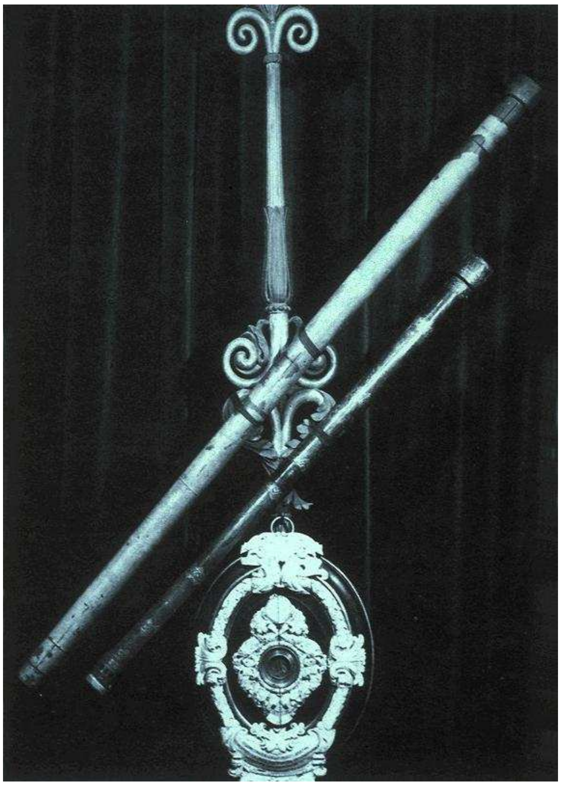


Tycho Brahe (1546–1601): Visual planetary positions of highest precision (arcminutes. . .)

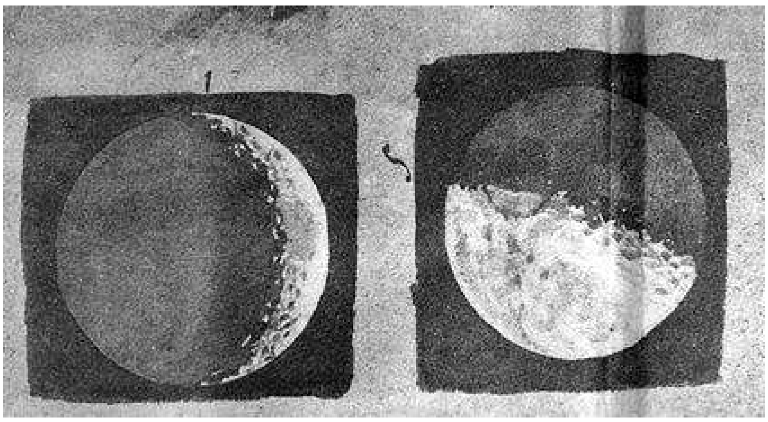
$\Longrightarrow$ culmination of *visual* optical astronomy.

http://galileo.rice.edu/sci/brahe.html

Optical Telescopes, I

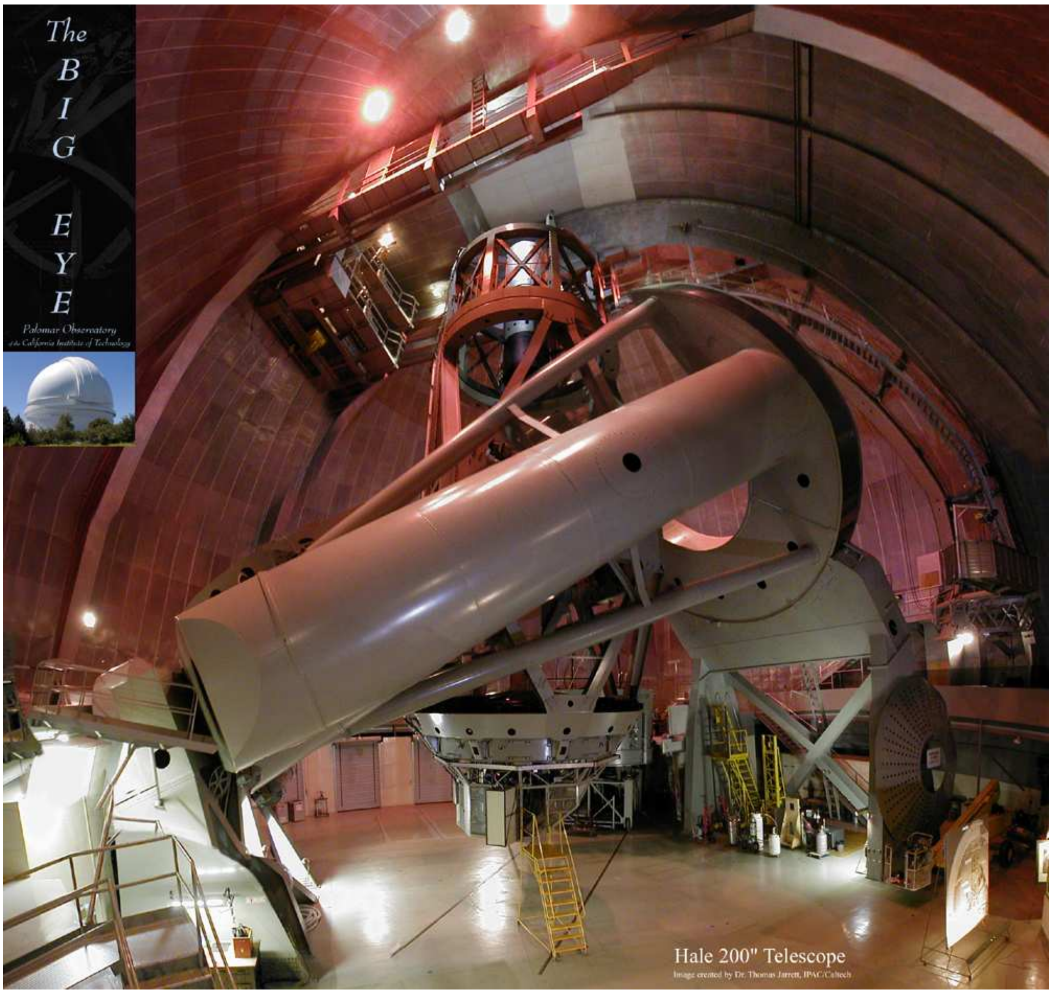


1600s: Invention of telescope (Lipperhey), first uses in scientific measurements.



Example of Galileo's drawings of the moon

http://galileo.rice.edu/sci/instruments/telescope.html

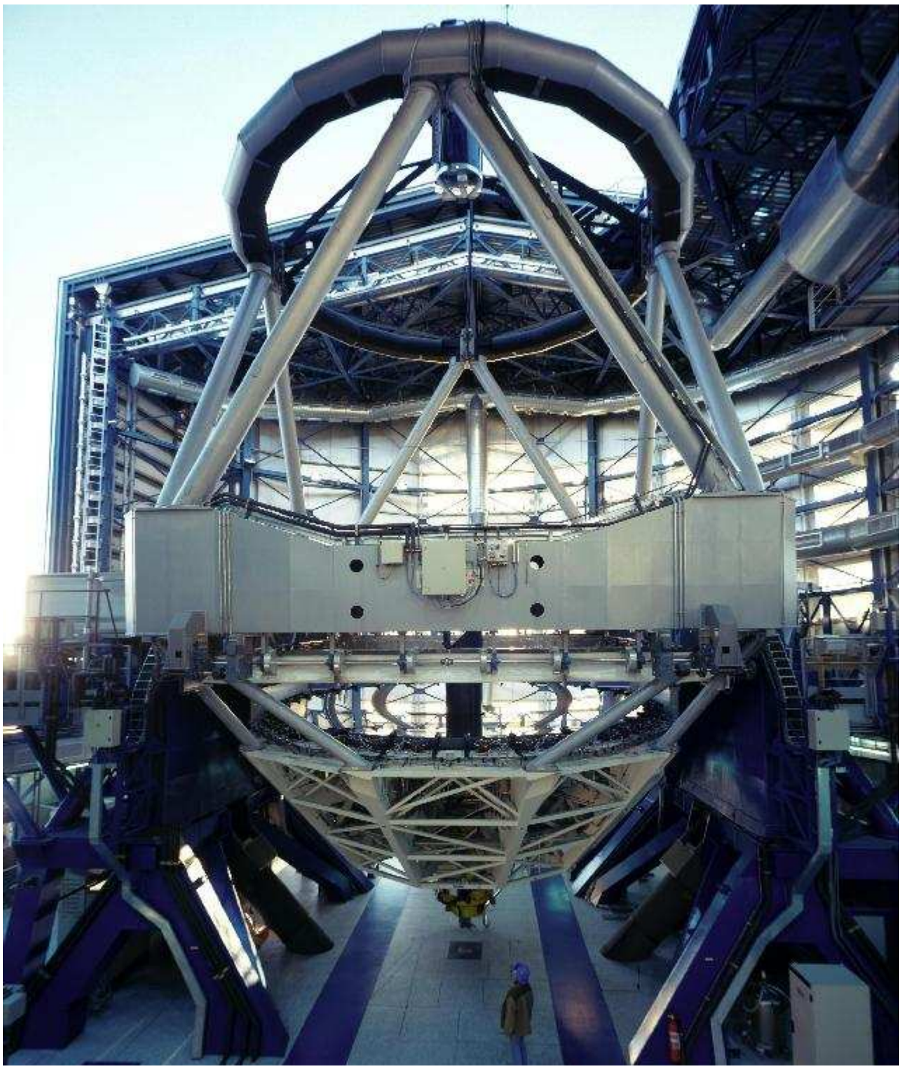


1940s and 1950s: 200$''$ telescope on Mt. Palomar: gigantic light collecting area

Since mid-1980s: new technologies to build mirrors

$\Longrightarrow$ era of 8–10 m telescopes (e.g., ESO Very Large Telescope)

"Light buckets"



Kueyen, one of the four ESO Very Large Telescopes (8 m mirror diameter)

The Case for Space, I

Ground based optical facilities are very successful, but Earth's atmosphere is a big problem.

Astronomical seeing: Eddies in atmosphere result in blurring, telescope resolution limited to $\sim 0.5''$

Compare to theoretical resolution ("Diffraction limit"):

$$\theta = 1.22 \frac{\lambda}{d} \qquad (1.5)$$

where θ: resolution (in rad), λ: wavelength, d: diameter of telescope.

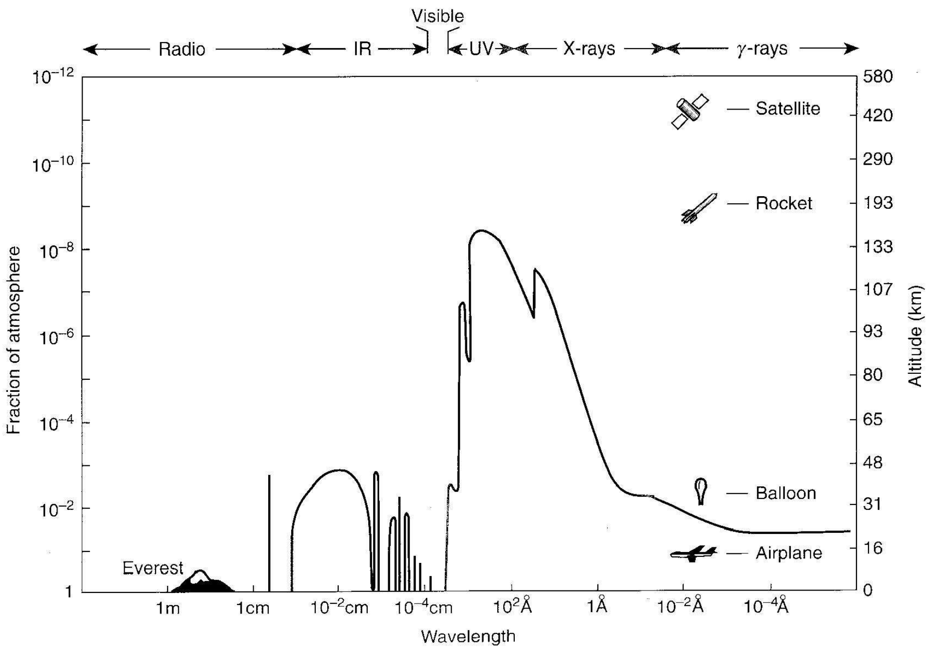
For optical light ($\lambda = 500\,\mathrm{nm} = 5 \times 10^{-7}\,\mathrm{m}$), the theoretical resolution of a 8 m mirror is $\theta = 7.6 \times 10^{-8}\,\mathrm{rad} = 0.016''$

In optical astronomy, space observations allow better spatial resolution than ground based observations.

Correcting for seeing is in principle possible (at least in infra red), but still technologically very challenging.

since 1990: *Hubble* Space Telescope (2.4 m diameter)

Earth's Atmosphere



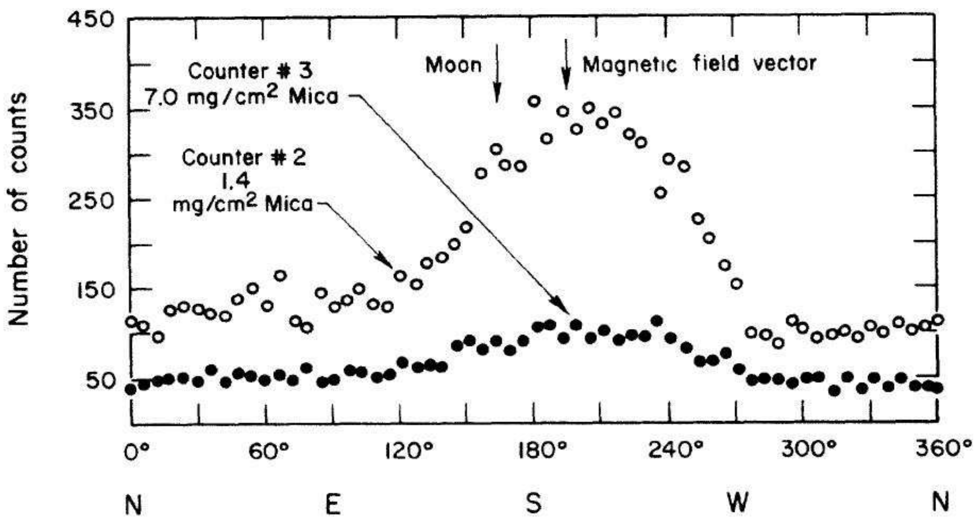
Charles & Seward, Fig. 1.12

Earth's atmosphere is opaque for all types of EM radiation except for optical light and radio.

Major contributer at high energies: photoabsorption ($\propto E^{-3}$), esp. from oxygen (edge at $\sim$500 eV). See later.

$\Longrightarrow$ If one wants to look at the sky in other wavebands, on *has* to go to space!

History of X-ray Astronomy



First discovery of X-rays from the Sun in 1946ff. (Friedman et al., Navy Research Lab, using left-over V2 rockets).

1962 June 18: Searches for extrasolar X-rays (Giacconi, Rossi) using Aerobee rockets.

Tried seeing fluorescence of solar X-rays from the moon, but discovered very bright source: Scorpius X-1

UHURU

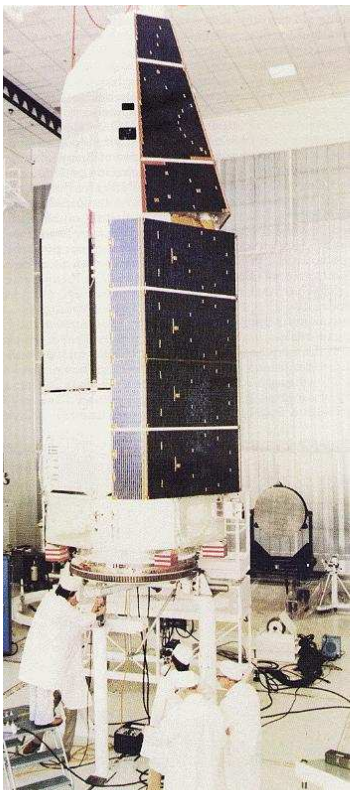
NASA/GSFC

12 Dec 1970: launch of *UHURU* (swahili for “Freedom”): First satellite sensitive in X-rays

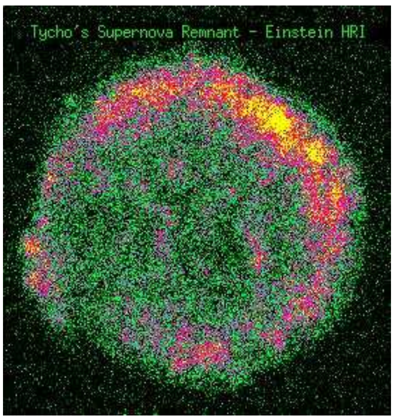
Discovery of many bright X-ray sources (e.g., Cygnus X-1, Hercules X-1, etc.).

Full list of sources summarised in the 4th *UHURU* catalog (339 sources).
Source names: e.g., 4U0115+63, 4U1957+11,. . .

Einstein



NASA/GSFC



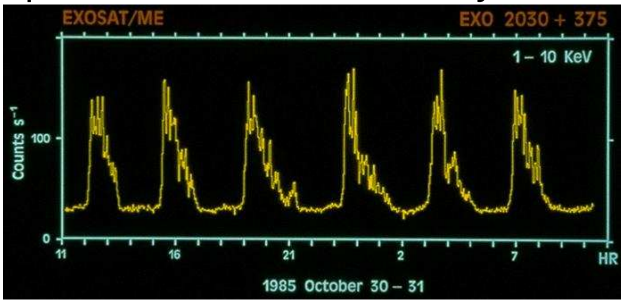
Tycho Supernova-Remnant with *Einstein*.

12 November 1978 – April 1981: *HEAO-2/Einstein* (NASA): First imaging telescope in space (soft X-rays; 0.2–20 keV)

EXOSAT

ESA

26 May 1983 – 9 April 1986:
EXOSAT
Large European X-ray Satellite,
operated like an observatory.



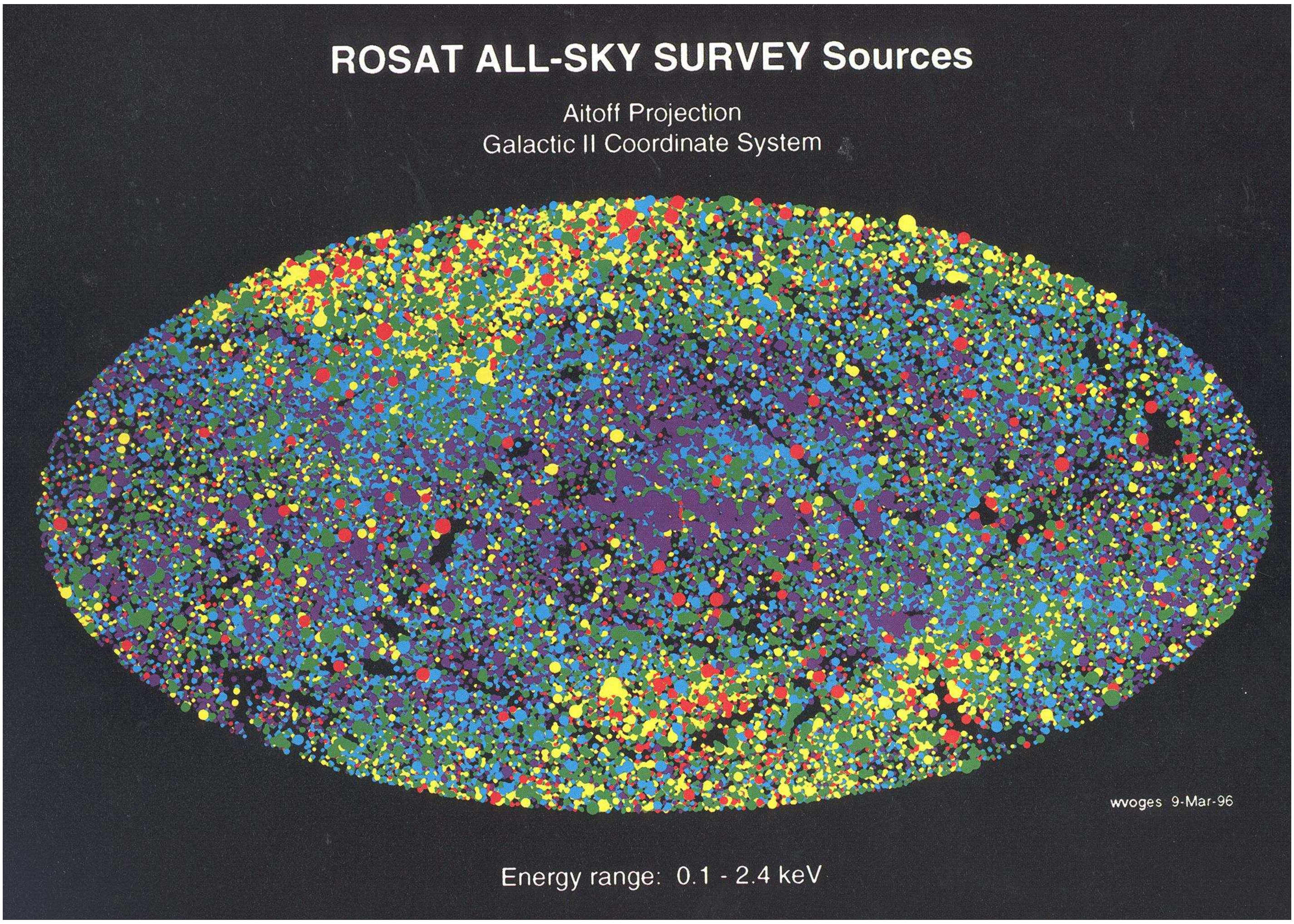
Major studies of X-ray bursts (thermonuclear explosions on the surfaces of neutron stars) and discovery of Quasi-Periodic Oscillations (high frequency oscillations in X-rays from neutron stars).

ROSAT

Univ. Leicester/MPE

1 June 1990–12 February 1999:
ROSAT (Röntgensatellit):
German/UK/US satellite for soft X-rays (0.1–2.5 keV).

RASS: *ROSAT* All Sky Survey:
Catalogues of 105924 faint X-ray and 18811 bright X-ray sources
$\Longrightarrow$ Largest catalogue of X-ray sources to date.



Early map of the *ROSAT* catalogue (75000 sources)

Chandra