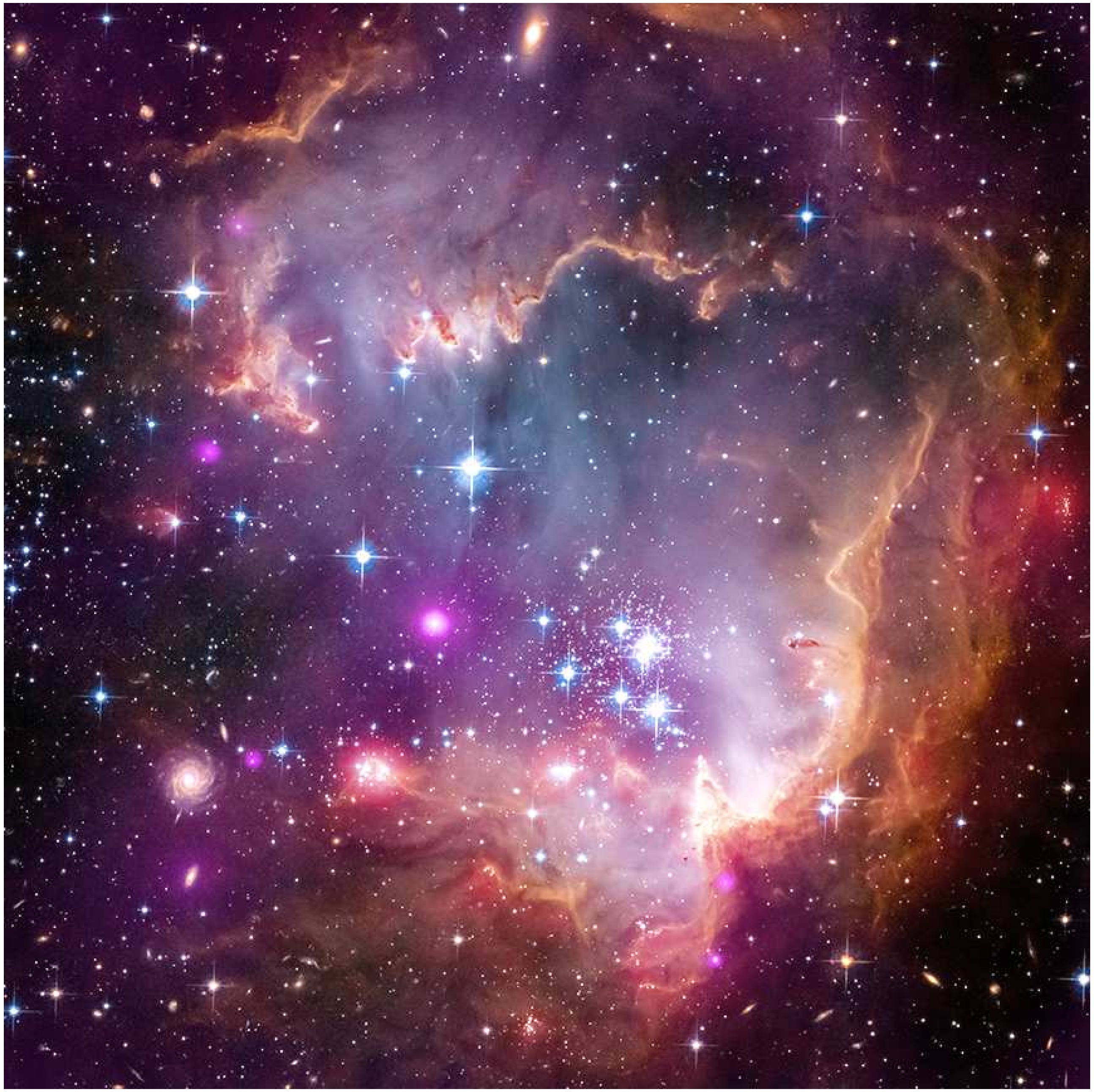
The X-Ray Universe



Potsdam University

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Sommersemester 2017

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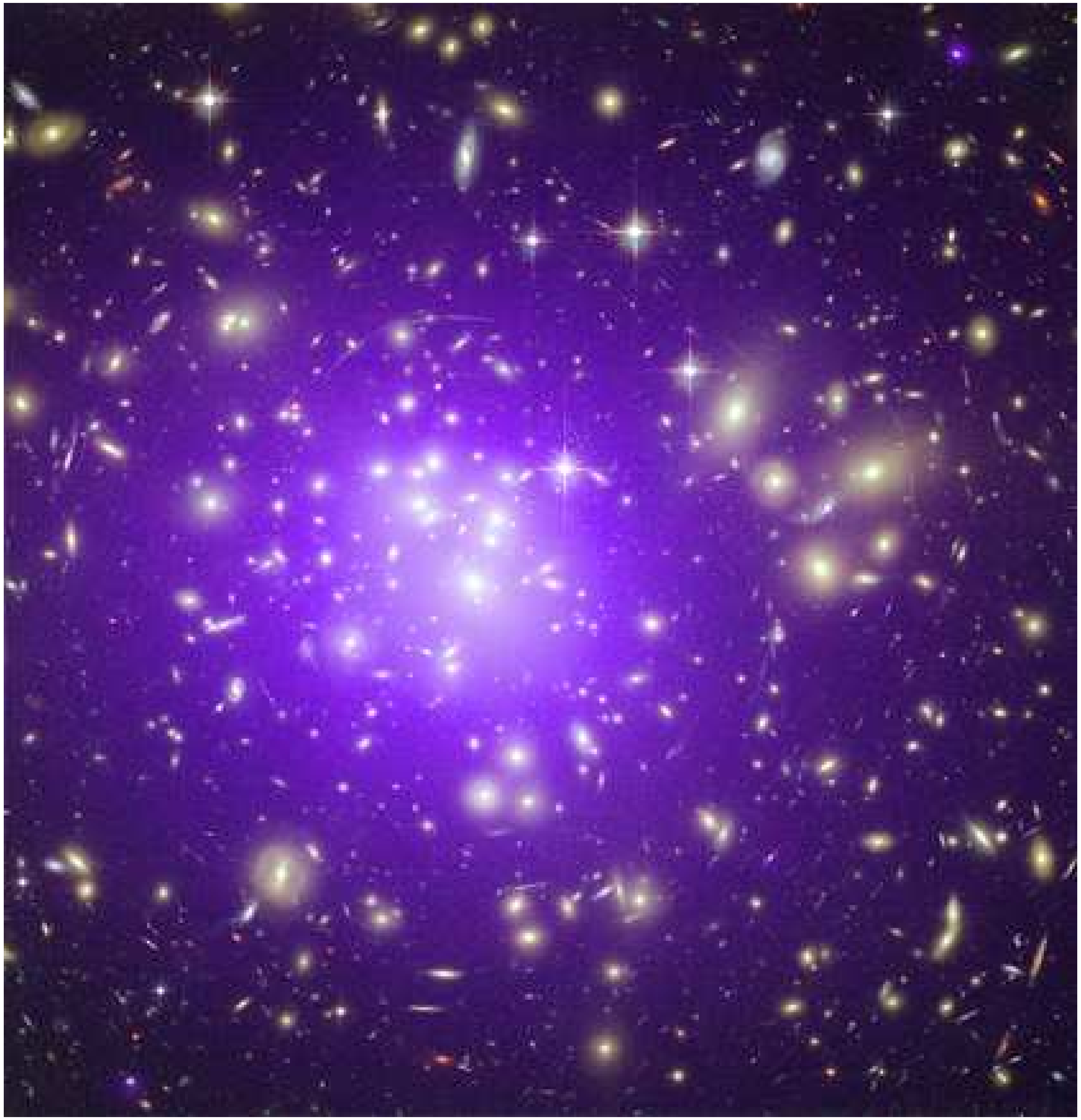
astro.physik.uni-potsdam.de/~lida/x-ray.html

Chandra X-ray, HST optical, Spitzer IR
NGC602 in the SMC
d=60pc

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= 2.3×10^9 ly

Frontiers of observational astrophysics

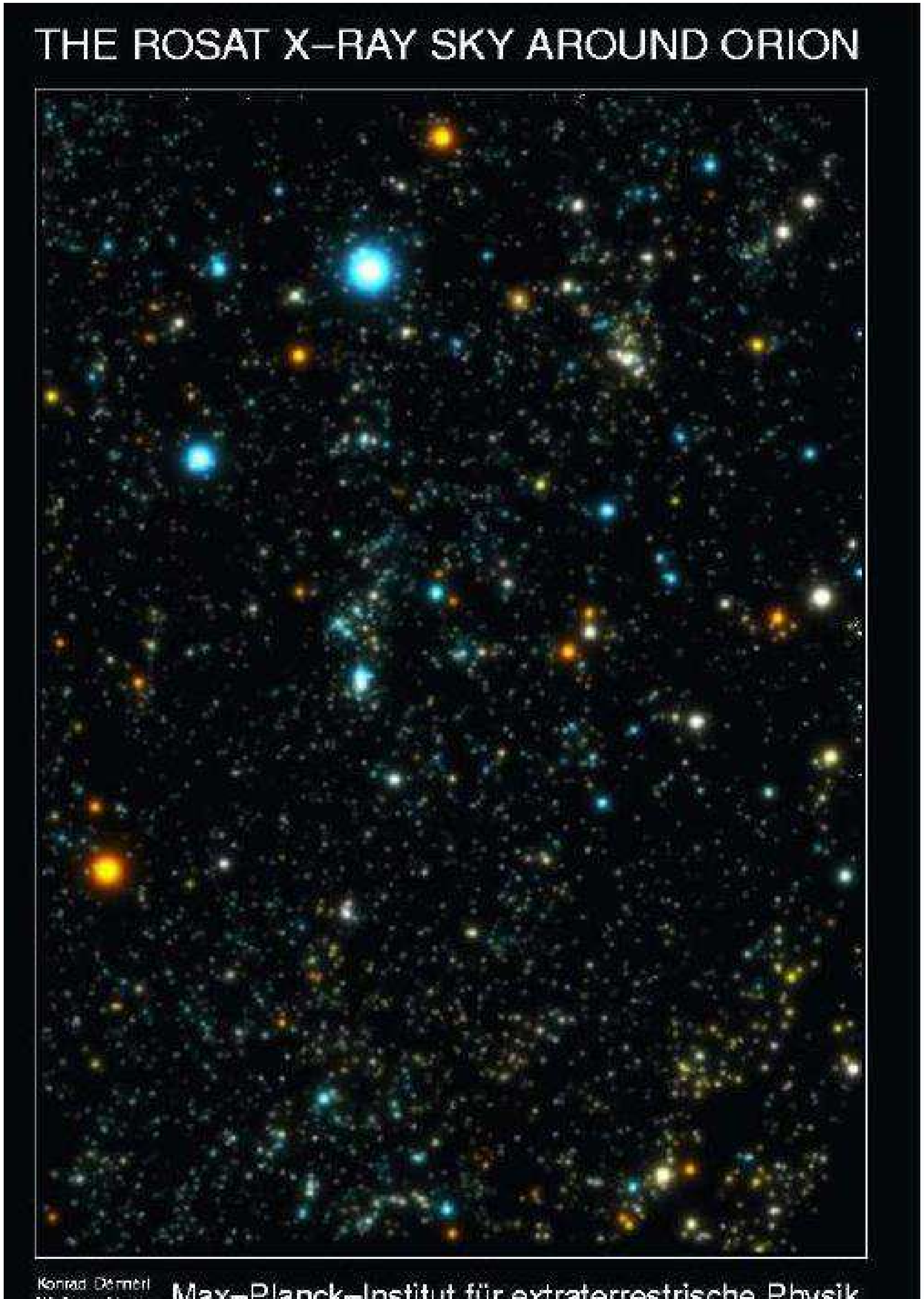
Five active missions: most obsevred band of EM spectrum in space from space

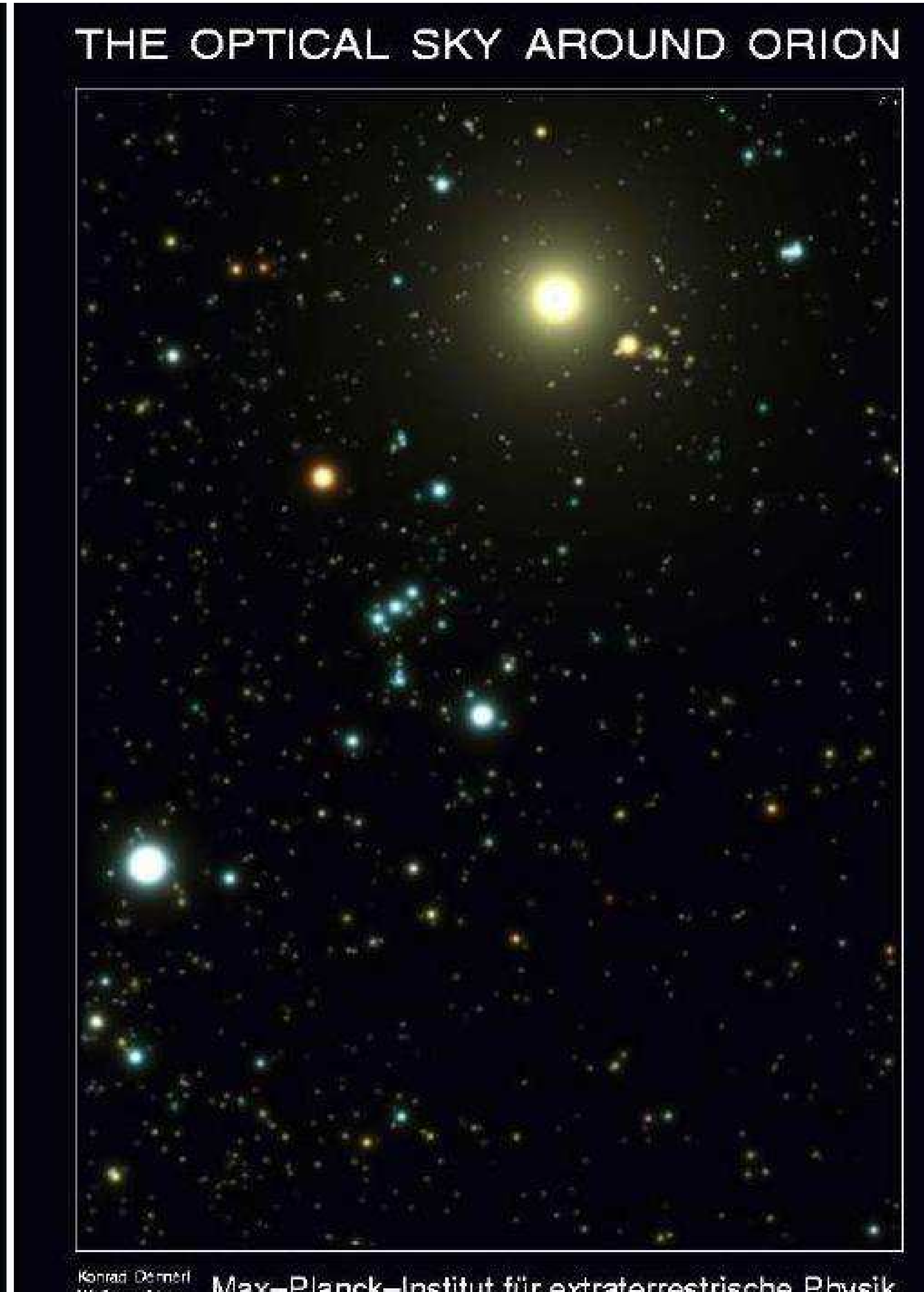
New missions planned

XMM-Newton (ESA) 2000

Nu-Star (NASA) 2012

Chandra (NASA)1999

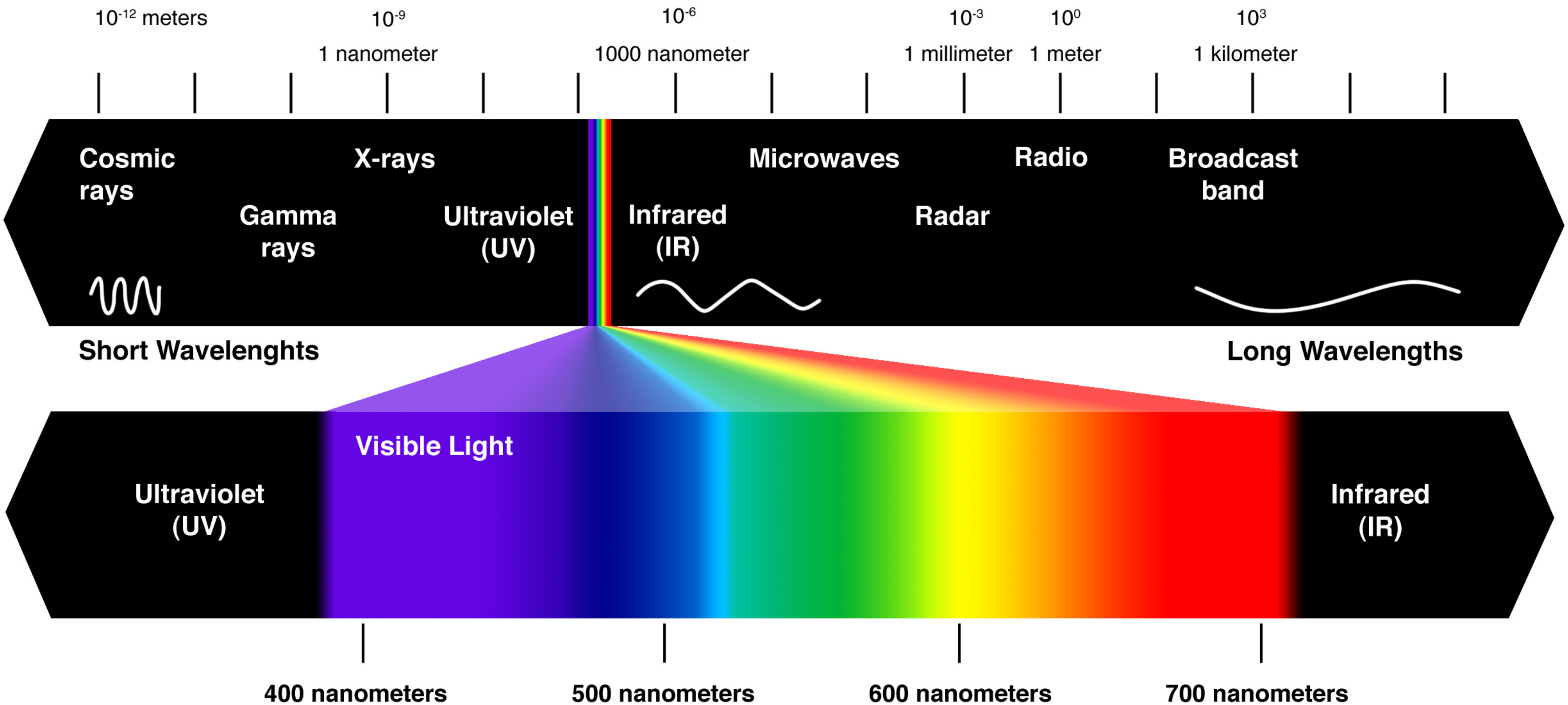

THE ROSAT X-RAY SKY AROUND ORION
Konrad Dennerl
Wolfgang Voges
Max-Planck-Institut für extraterrestrische Physik


THE OPTICAL SKY AROUND ORION
Konrad Dennerl
Wolfgang Voges
Max-Planck-Institut für extraterrestrische Physik

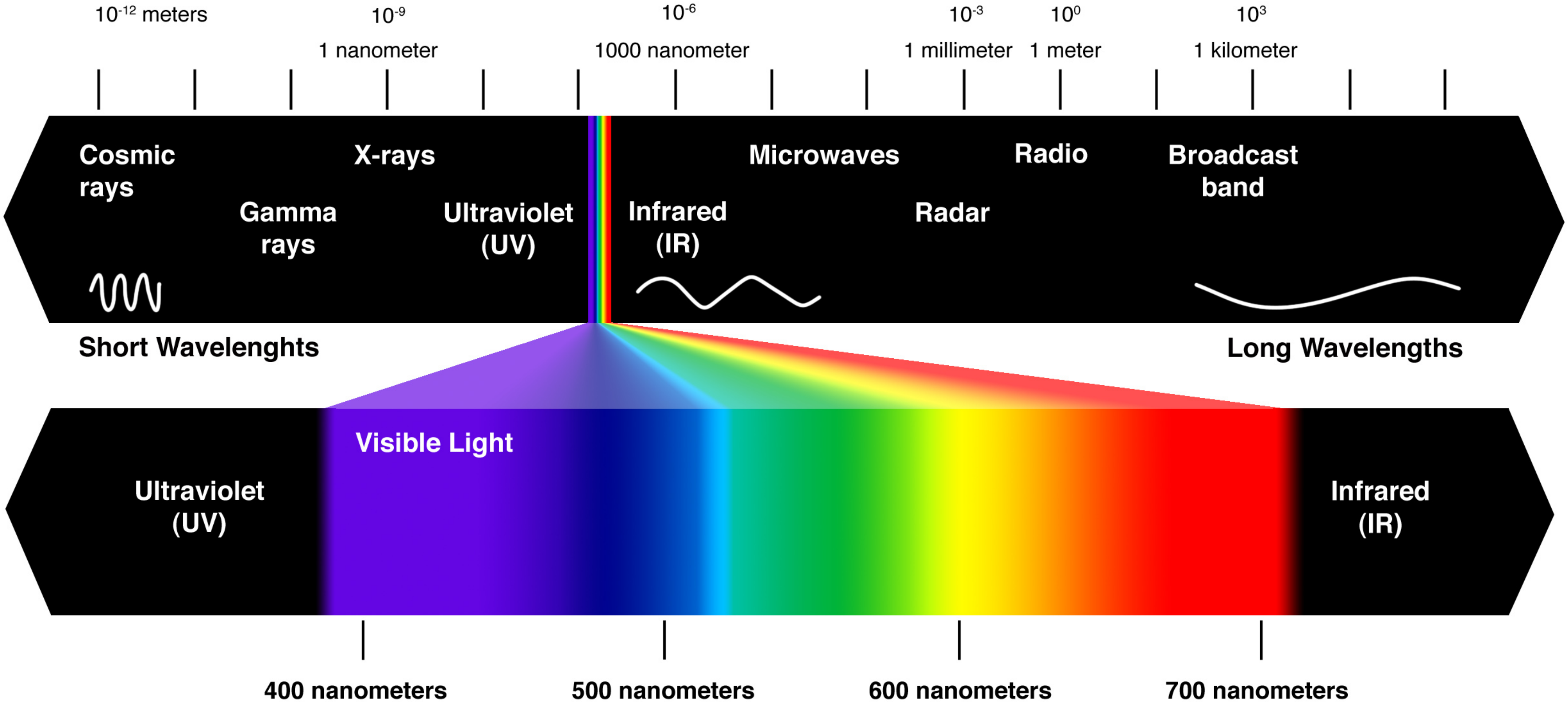
- Introduction
  - Introduction. History
- X-Ray Detectors and Telescopes
  - Proportional Counters, Scintilators, CCDs, Wolter Telescopes
  - Codeded Mask Imaging, current telescopes
- X-Ray processes and plasmas
  - Physics of X-ray emission
- X-Rays accross Hertzsprung-Russell Diagram
  - Stars: low and high mass
- Stellar remnants
  - Supernovae
  - Black holes, neutron stars, white dwarfs
- Active galaxies and Cosmology
  - AGN
  - Galaxy clusters

Units and language of X-ray astronomy

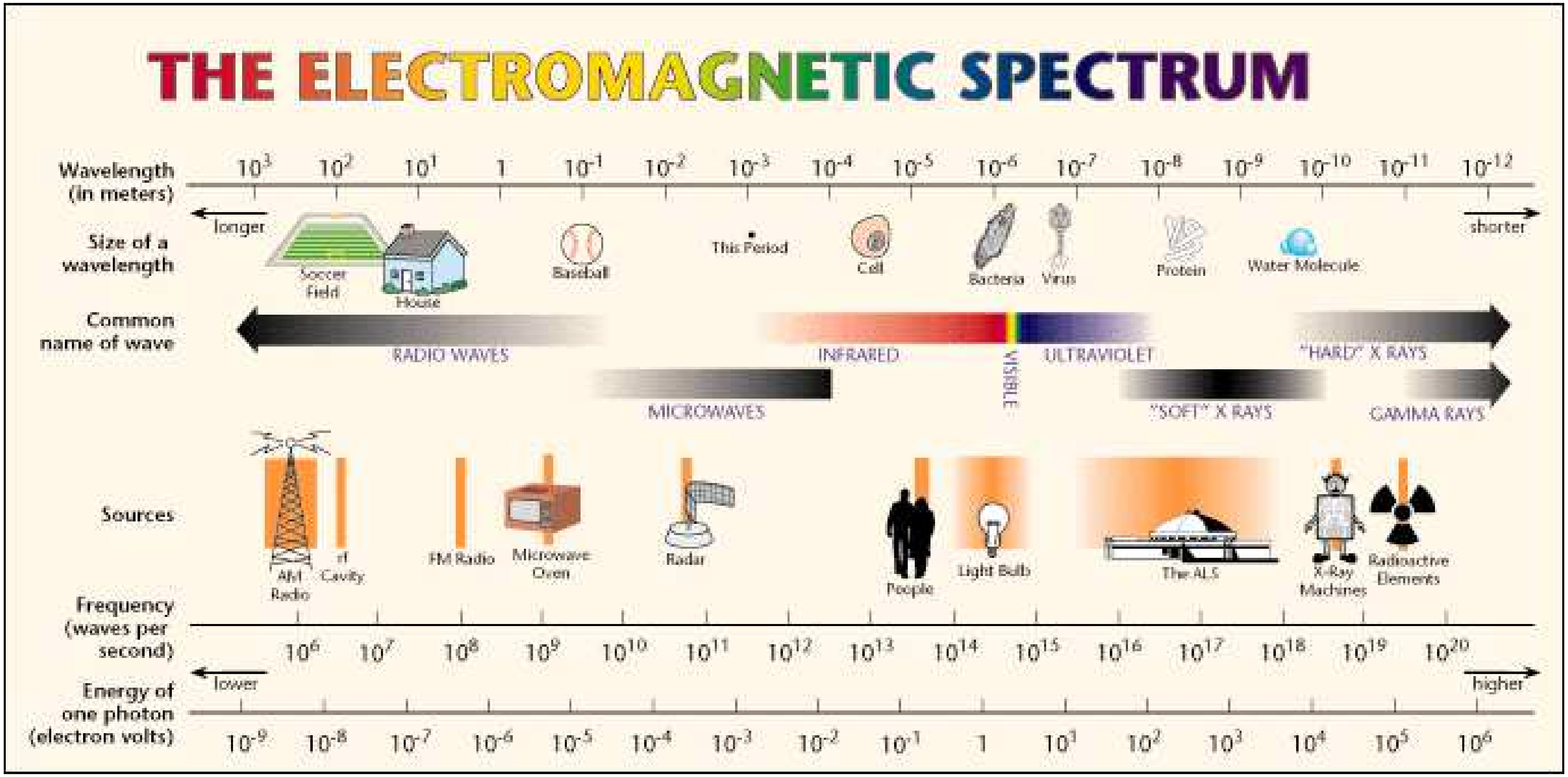
- Positions
  - Most often equatorial coordinates (α, β)
  - Also Galactic coordinates (b,l)
  - Angular distances in arcsec
- Distances
  - Parsec - distance at which 1 AU subtends 1 arcsec
  - 1 pc = 3.1×10^{18} cm =3.26 ly
- Energy and Power (or Luminosity) (**cgs!**)
  - 1 keV=1.6 $\times 10^{-9}$ erg, 1 erg = 10^{-7} joule
  - 1 watt = 10^{7} erg/s
- Flux (**cgs!**)
  - 1 Jansky = 10^{-26} watt/m^2/Hz
  - 1 μJy = 2.42 $\times 10^{-11}$ erg/cm^2/s/keV
  - 1 Crab = 1060 μJy



- Most information about the Universe: EM radiation
- Different physics: different type of radiation
- Measurable quantities:

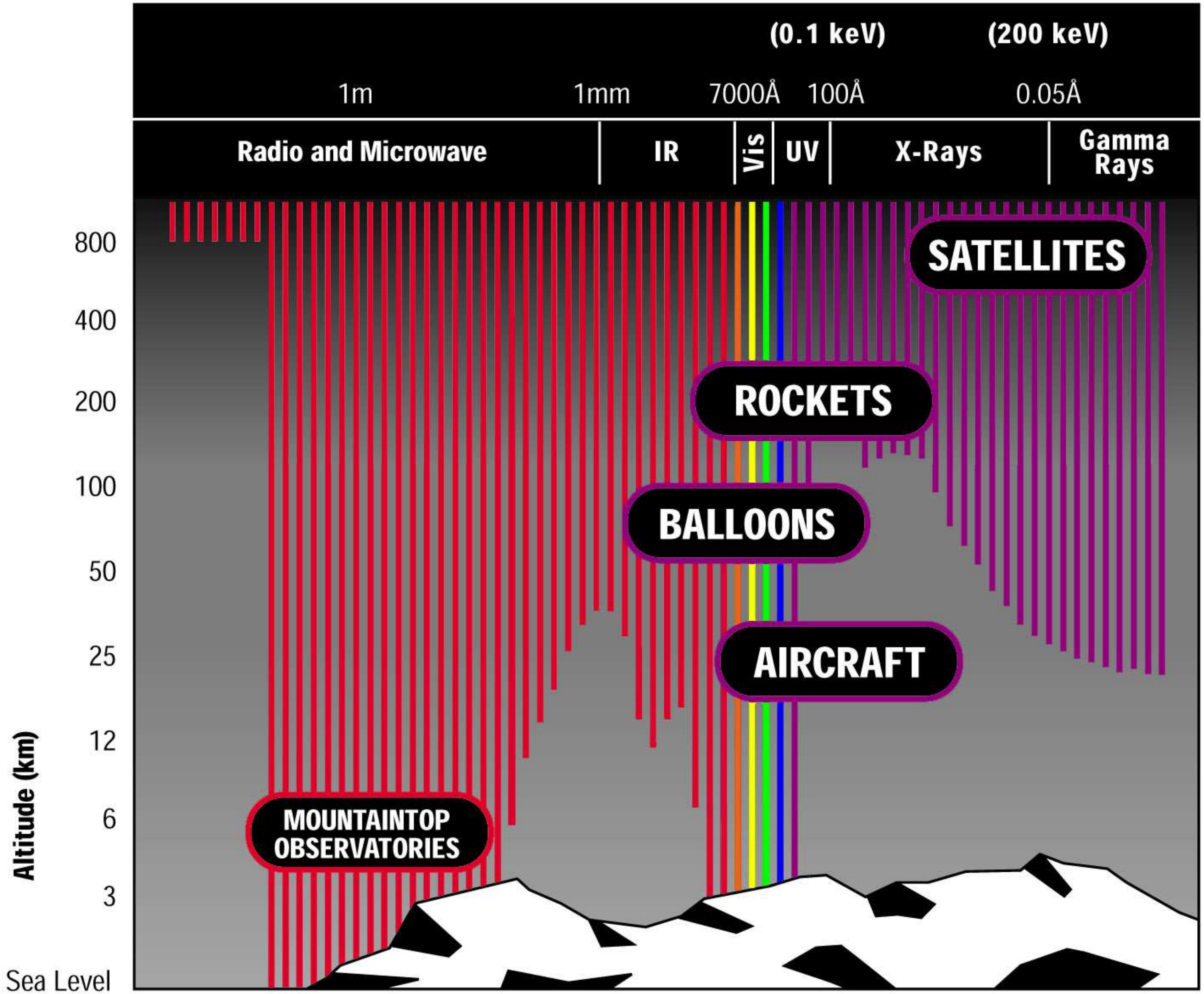


- Most information about the Universe: EM radiation
- Different physics: different type of radiation
- Measurable quantities: wavelength, flux, polarisation



- "Soft" X-rays 0.01 .. 1 keV
- "Hard" X-rays > 1 .. 10 keV
- Low energy γ-rays 500 keV (rest enerfy of electron) .. 10 MeV
- High energy γ-rays > 1 GeV (rest enerfy of proton)
- Most of the Universe consist of ?
- Its ioization potential is ?

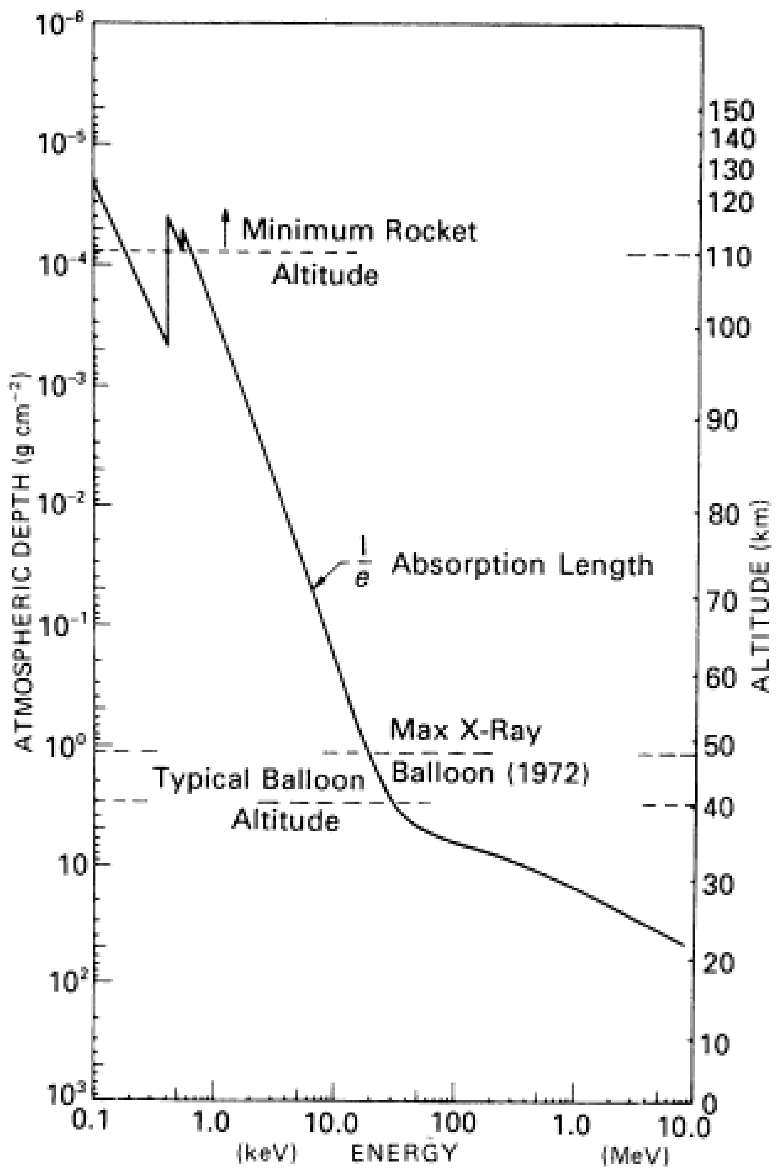
Attenuation of photons in the atmosphere I



Attenuation of photons in the atmosphere II

Attenuation of photons in the atmosphere

Attenuation of photons in the 1972 COSPAR International Reference Atmosphere with $1/e$ absorption length plotted as a function of energy and altitude or atmospheric depth.



- Optical depth $\tau_E = \int \kappa_E \rho ds$
- κ_E mass absorption coefficient
- $[\kappa_E]$=cm^2 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)

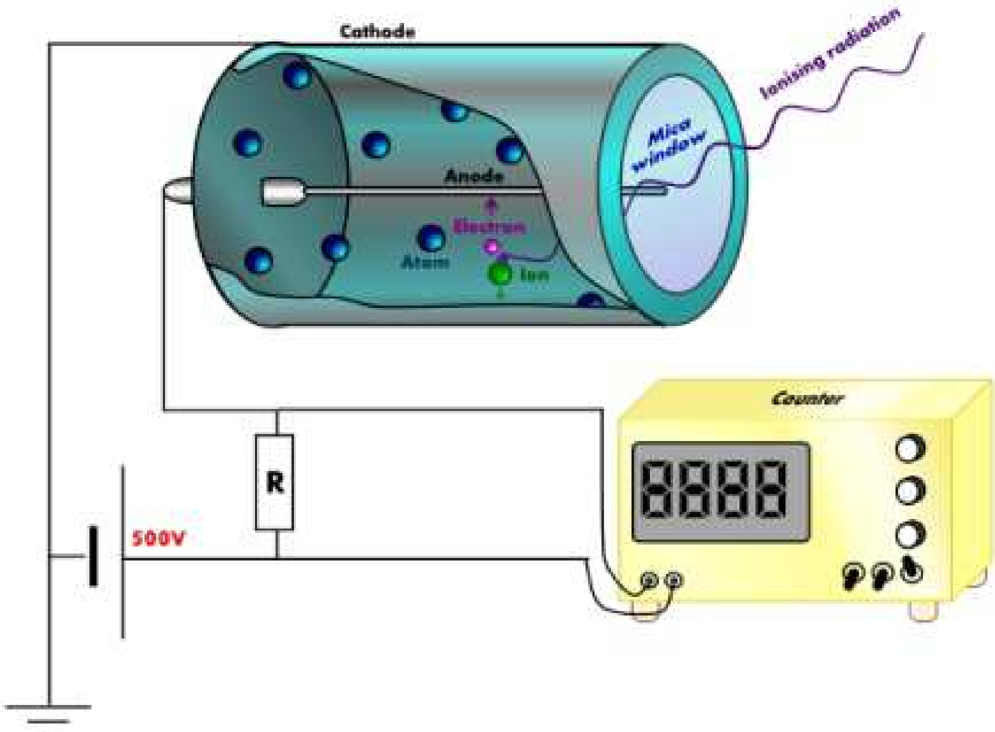
1901 Röntgen was awarded
the very first Nobel Prize in Physics

"in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him"

Geiger-Müller counter

1908 first principle

1928 Geiger-Muller tube



Counter: no energy informaiton, no image, limited info on direction, bad time resolution

Rockets Vergeltungswaffe 2

Vergeltungswaffe 2 captured by allies after the WWII

Navy Reseach 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

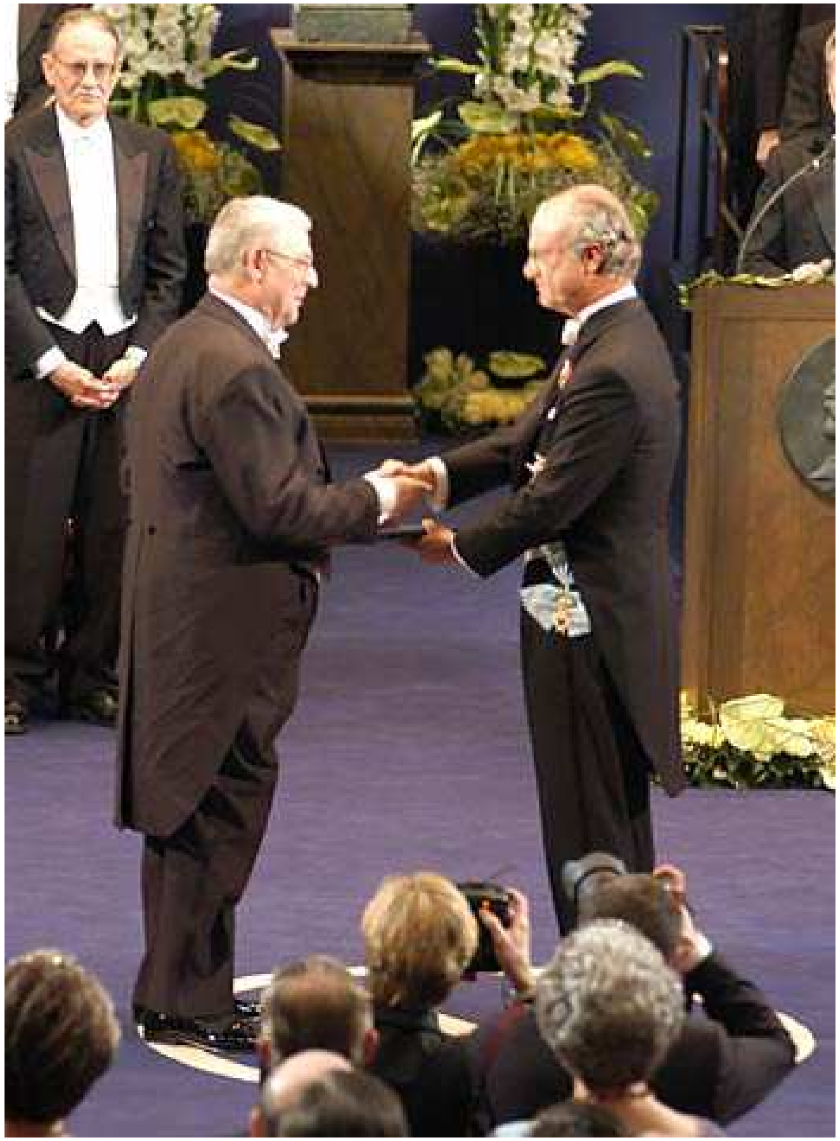
NB! It is still not understood how solar corona is heated

Focusing X-ray optics

- Wolter, H. (1952) "Glancing Incidence Mirror Systems as Imaging Optics for X-rays". Ann. Physik 10: 94.
- Wolter, H. (1952) A Generalized Schwarzschild Mirror System For Use at Glancing Incidence for X-ray Imaging. Ann. Physik 10: 286.

Walter designed a system of mirrors that satisfied the Abbe sine condition (i.e. free of both spherical aberration and coma). The three simplest designs are known as Wolter telescopes of types I, II and III.

First astrophysics How to get Nobel Prise



2002: Giacconi recieves NP from the king of Sweeden

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: $L_X = 10^9\ L_X^{sun}$

see www.nobelprize.org/nobel_prizes/physics/laureates/2002/giacconi-lecture.html

Firts science results

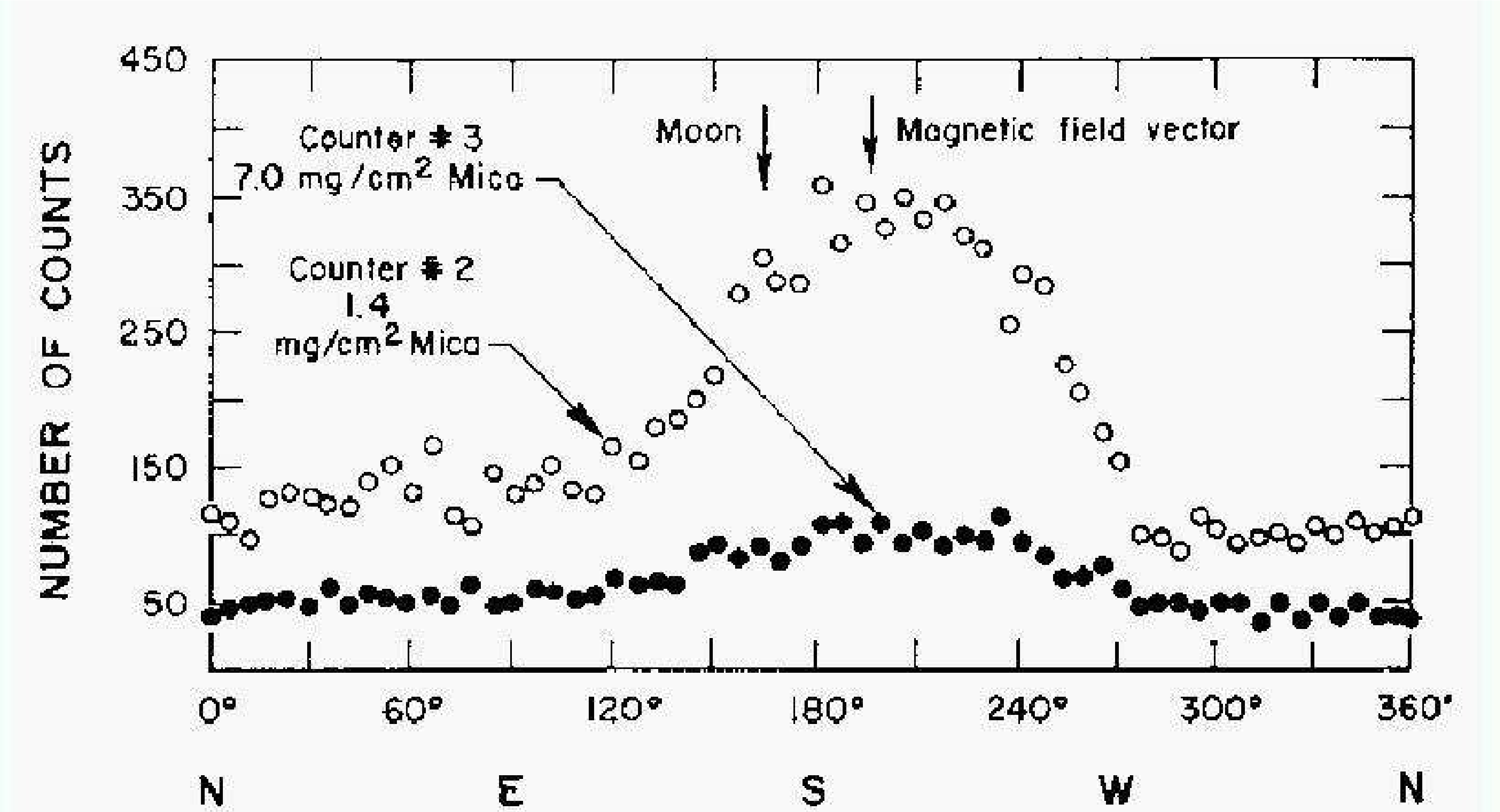


Figure 2. The first observation of Sco X–1 and of the x–ray background in the June, 12, 1962 flight. From Giacconi, *et al.*, 1962.

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

Shklovsky 1967: Sco X-1 is a binary containing neutron star

1967: Hewish discovery of pulsars

Note the X-ray background

UHURU

src. Wikipedia

Rockets: 5 min above 100 km for each launch

Need a satellite!

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

First X-ray space observatory
Angular resolution 0.52 degree

Increased time for obs by 10^5 times

Sky survey: UHURU Dec 1970 - March 1973

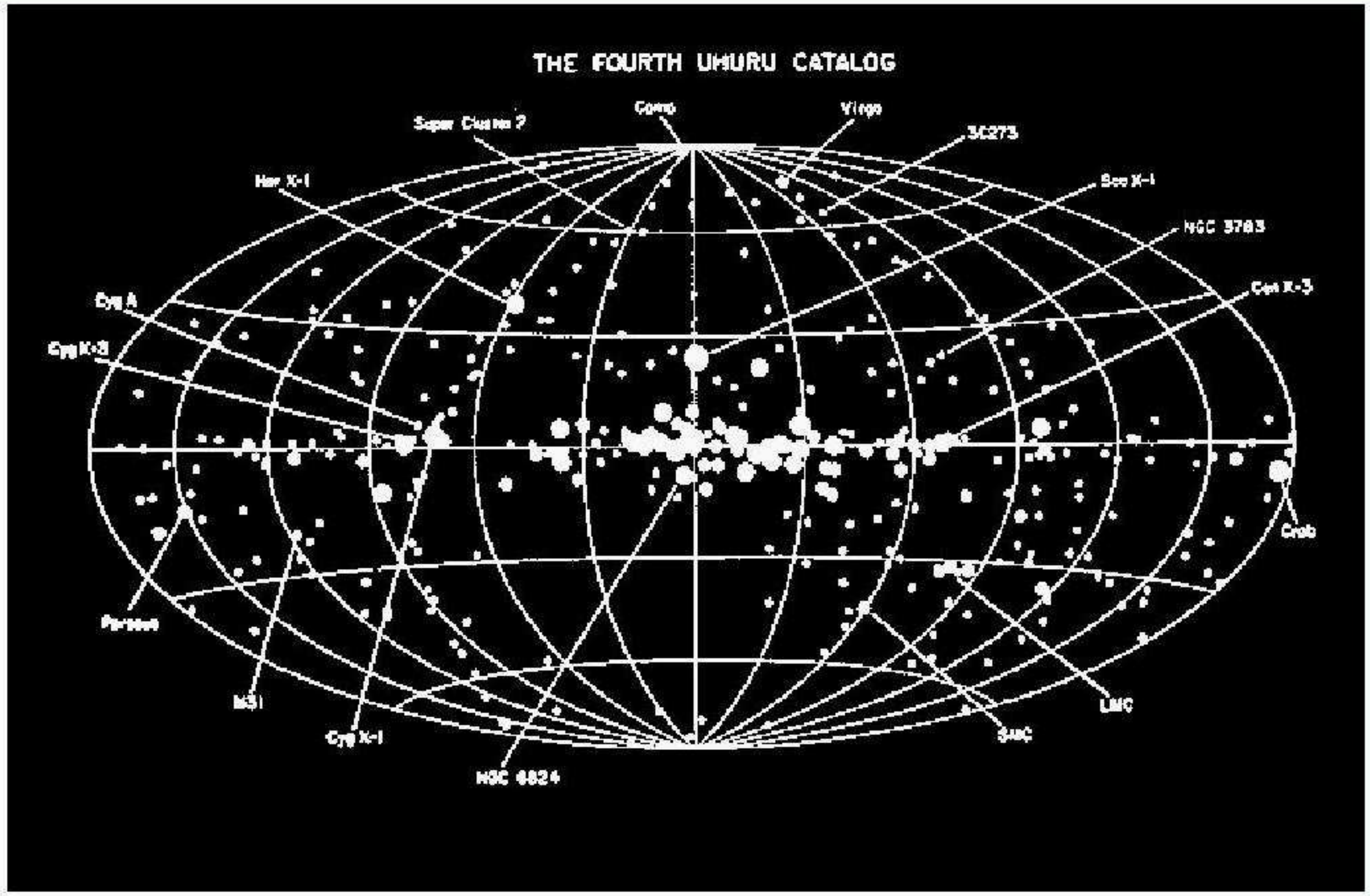


Figure 4. The x–ray sources observed by UHURU plotted in galactic coordinates. The site of the dot is proportional to intensity on a logarithmic time scale. From X-ray Astronomy (Eds. R. Giacconi, H. Gursky), 1974, Riedel, Dordrecht, p. 156.

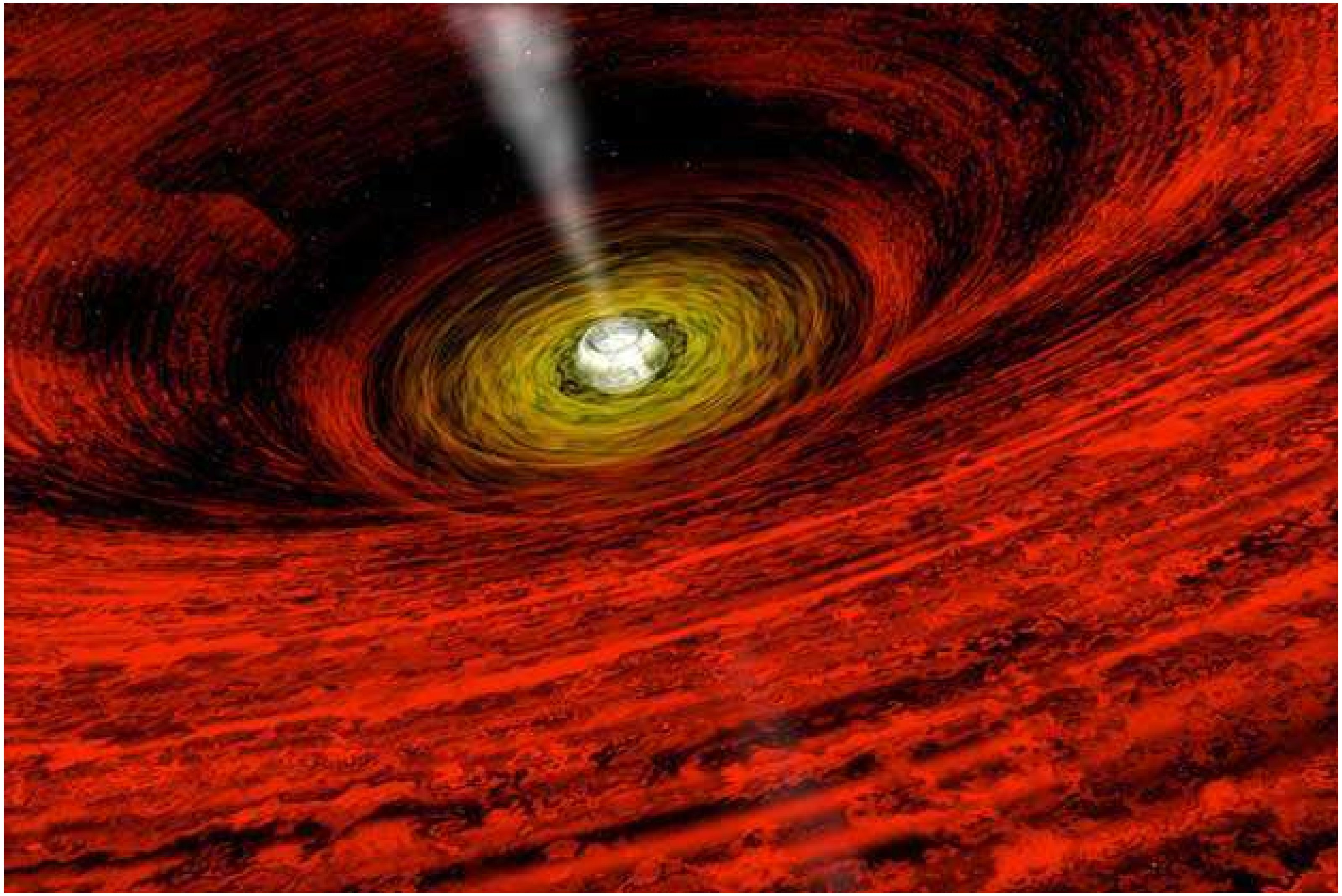
Band 2 .. 20 keV, flux 1/10,000th of Sco X-1, A = 0.084 m^2

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..

by 1975 in was known



Artist impression

Many X-ray sources

Galactic: accreting NS and BH in binary systems

Extragalactic: galaxies

Mainly - emission of hot gas with $T=10^{6..7}$ K

Observational boom

Selected Past Missions

- ANS – Lifetime: Aug 1974 – June 1977, Energy Range: 0.1 – 30 keV and 1500–3300 Angstoms
- Ariel V – Lifetime: Oct 1974 – Mar 1980, Energy Range: 0.3 – 40 keV
- 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
- BeppoSAX – Broad band energy. X–ray imaging the sources associated with Gamma–ray bursts and determining their positions with an unprecedented precision. (1996 – 2002)
- CGRO – Compton Gamma Ray Observatory. First Great Gamma–Ray observatory. Discovery of an isotropic distribution of the Gamma–ray bursts. (1991 – 2000)
- Copernicus – Lifetime: Aug 1972 – late 1980, Energy Range: 0.5 – 10 keV
- COS–B – Lifetime: Aug 1975 – Apr 1982, Energy Range: 2 keV – 5 GeV"
- DXS – 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
- EUVE – Extreme Ultraviolet Explorer. First dedicated extreme ultraviolet mission. (1992 – 2001)
- EXOSAT – Lifetime: May 1983 – Apr 1986, Energy Range: 0.05 – 20 keV, 90–hour highly eccentric Earth orbit
- Ginga – Lifetime: Feb 1987 – Nov 1991, Energy Range: 1 – 400 keV
- Granat – Lifetime: Dec 1989 – Nov 1998, Energy Range: 2 keV – 100 MeV
- Hakucho – Lifetime: Feb 1979 – Apr 1985, Energy Range: 0.1 – 100 keV
- HEAO–1 – Lifetime: Aug 1977 – Jan 1979, Energy Range: 0.2 – 10 keV
- HEAO–3 – Lifetime: Sep 1979 – May 1981, Energy Range: 50 keV – 10 MeV
- HETE–2 – Lifetime: Oct 2000 – Oct 2006, Energy Range: 0.5 – 400 keV, designed to detect and localize gamma–ray bursts
- OSO–7 – Lifetime: Sep 1971 – Jul 1974, Energy Range: 1 keV – 10 MeV
- 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–2 – Lifetime: Nov 1972 – Jun 1973, Energy Range: 20 Mev – 1 GeV
- SAS–3 – Lifetime: May 1975 – 1979, Energy Range: 0.1 – 60 keV
- Tenma – Lifetime: Feb 1983 – late 1984, Energy Range: 0.1 – 60 keV
- Uhuru – Lifetime: Dec 1970 – Mar 1973, Energy Range: 2 – 20 keV
- Vela 5B – Lifetime: May 1969 – Jun 1979, Energy Range: 3 – 750 keV

About 30 missions by mid 90s

First imaging telescope

Einstein Nov 1978 - April 1981

NASA, 0.2 - 20 keV

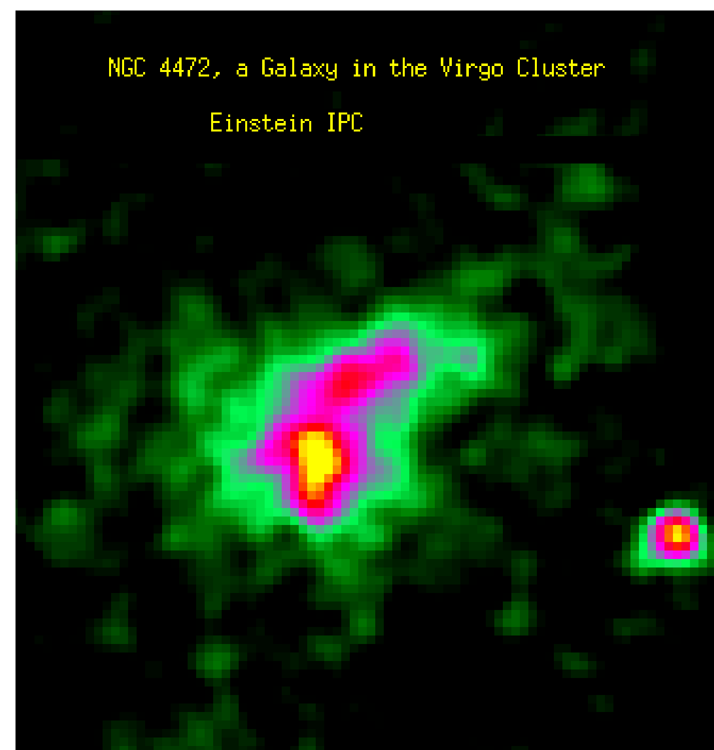
θ=2 arcsec

First X-ray spectra

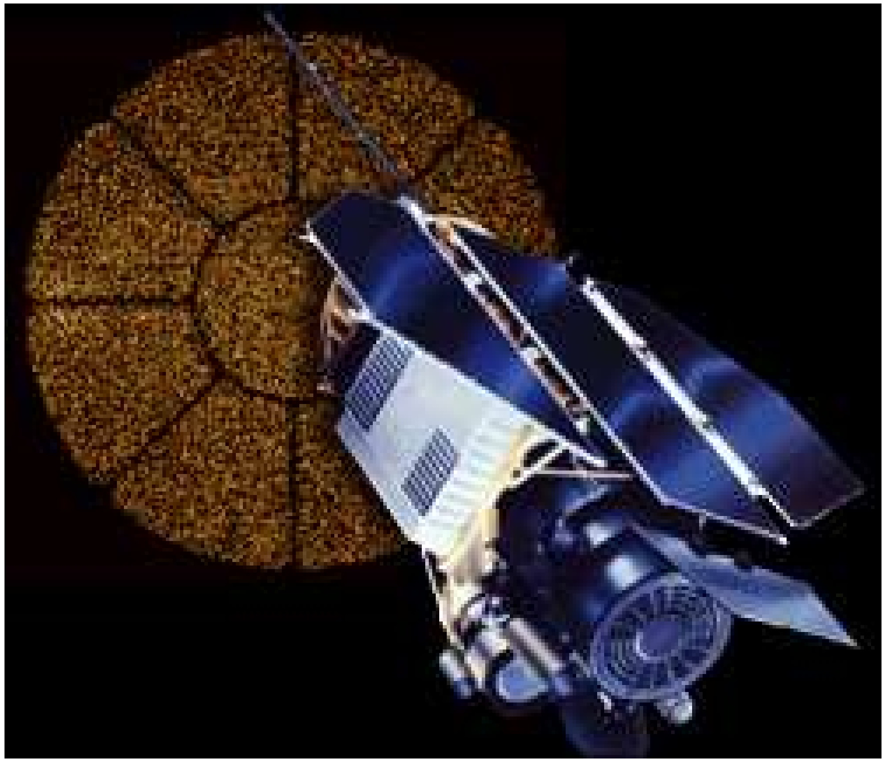
Coronae of stars

Supernova remnants

resolved extragalactic sources



Rosat



Röntgen Satellite 1990 - 1999

Germany, USA, UK 0.2 - 2.4 keV

θ=2 arcsec

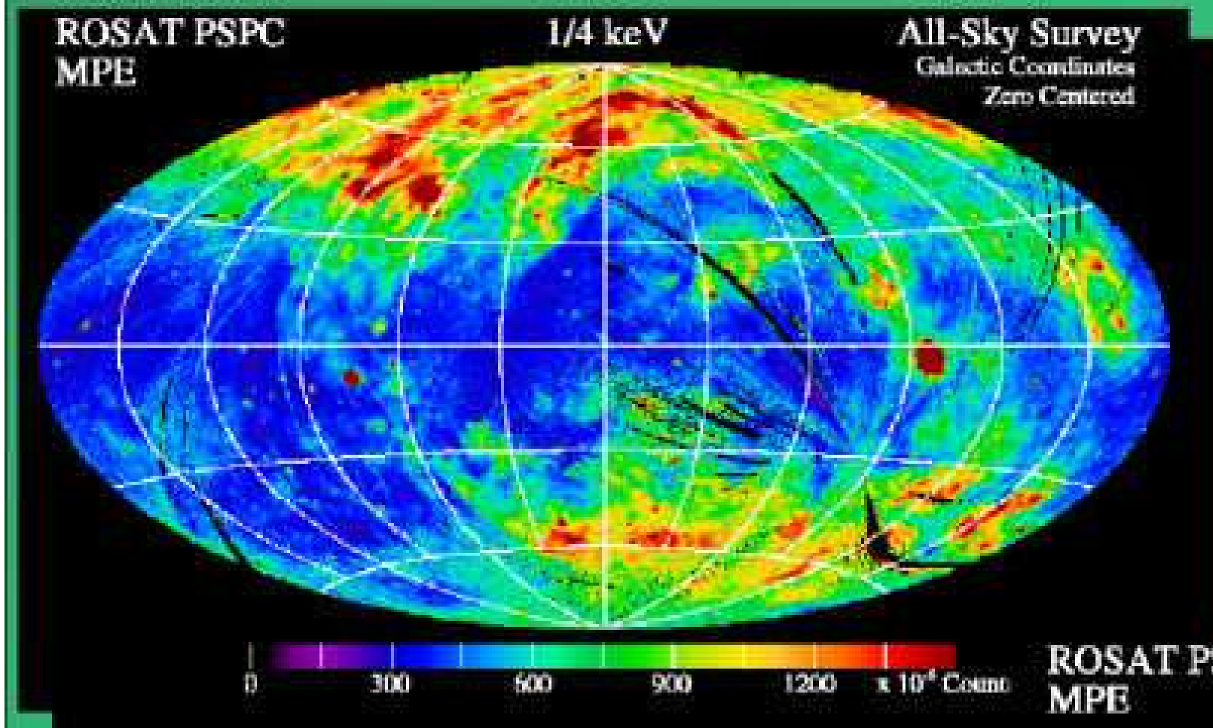
X-ray all-sky survey catalog, more than 150000 objects

detection of isolated neutron stars

Comets

The collision of the Comet Shoemaker-Levy with Jupiter

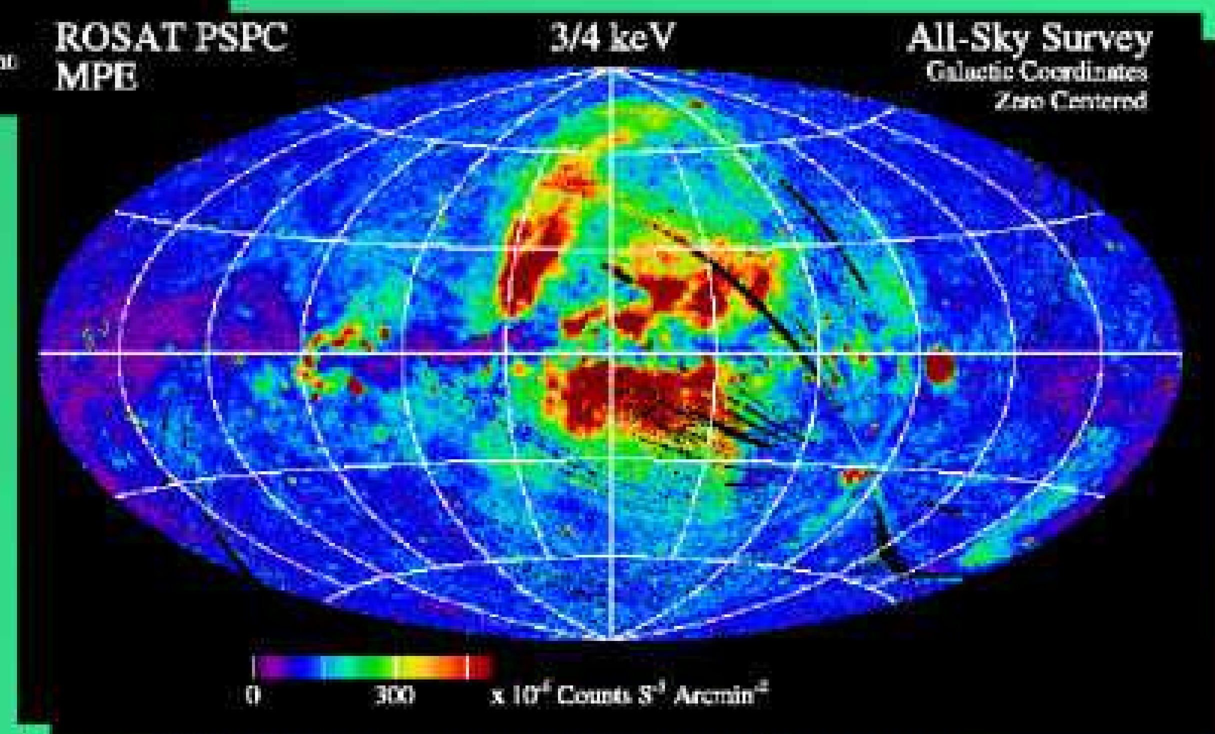
Initial Diffuse Background Maps from the ROSAT All-Sky Survey



- 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.

Top: Snowden et al. 1995, ApJ, 454, 643 Initial 1/4 keV diffuse background map from the ROSAT all-sky survey. It is in an Aitoff-Hammer equal-area projection, zero-centered, in galactic coordinates. Units are counts/s/arcmin^{-2}. The image shows considerable structure never before observed in this energy range.

Right: Map of the 3/4 keV diffuse background from the ROSAT allsky 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.



Major Modern Telescopes I XMM-Newton

X-ray Multi-Mirror 1999 -

ESA (with NASA) 0.2 - 12.0 keV

Orbit: 7000 km peregee

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 m^2 polished gold mirrors

Major Modern Telescopes I Chandra

NASA's Great Observatory 1999 -

NASA 0.2 - 12.0 keV

Orbit: 16000 km peregee

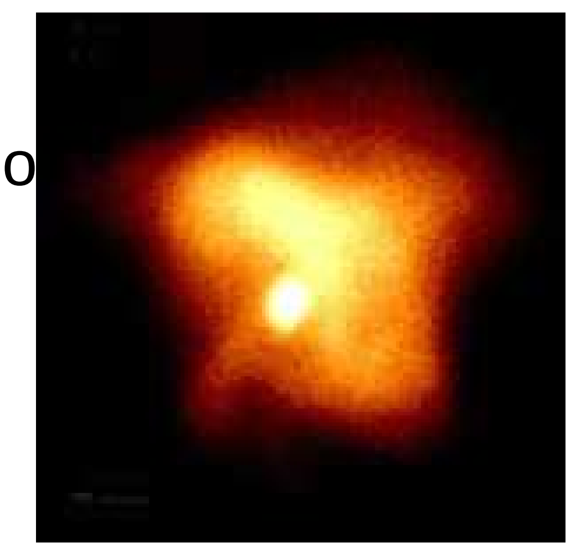
150 000 km apogee

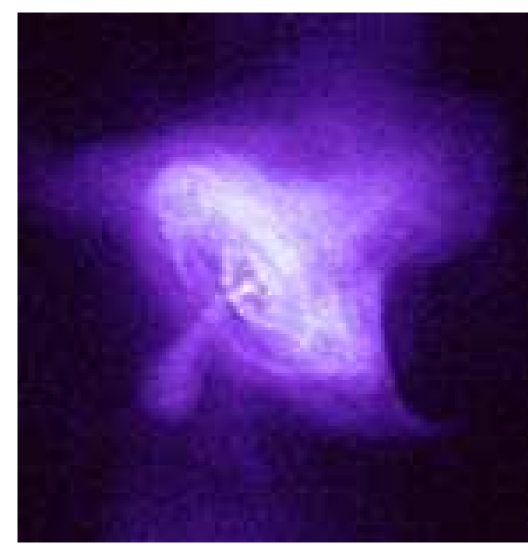
64 hours = 240 ksec

θ=0.5 arcsec (Unprecedented!)

best imaging for many decades to

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

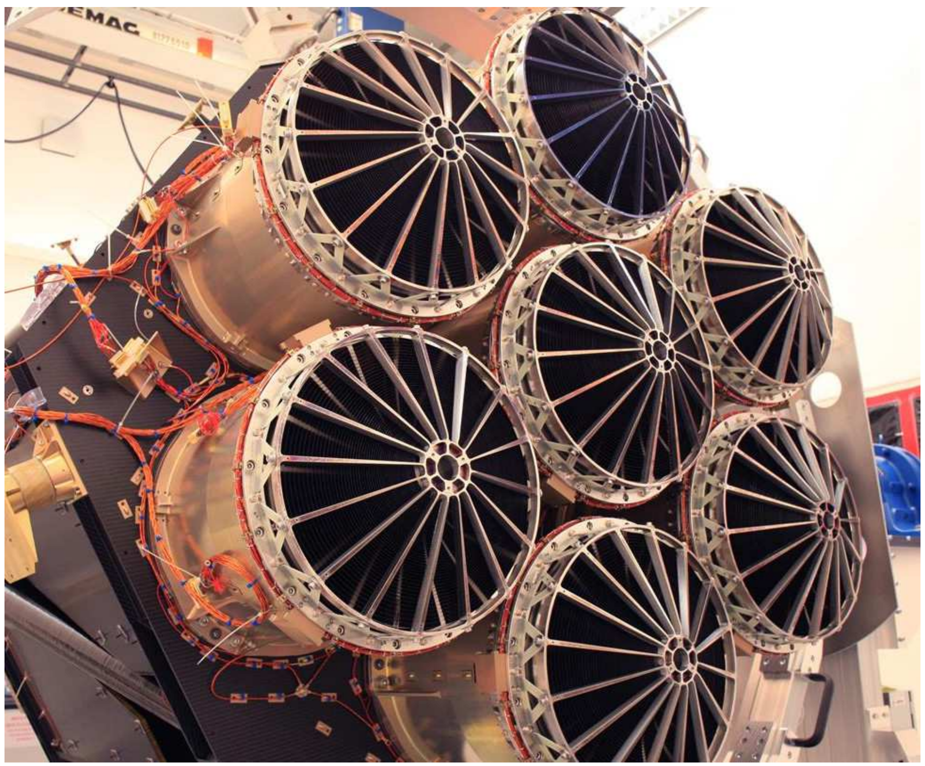
Eliptical galaxies and clusters:
the profile of dark matter halo, the enrichment hystory

Cooling flows provide estimate of the mean density in the Universe

eROSITA: all-sky X-ray survey in 0.2-10 keV (2018)

Extended Roentgen Survey
with an Imaging Telescope Array

Data access: German & Russian Consortia



All-Sky Survery: 4 years
full sky each 6 months
Followed by GO calls
pointed observations

$$L_{\rm Xmin} \approx 1.0 \times 10^{24} \times d^2[\rm pc]\ \text{erg s}^{-1}$$

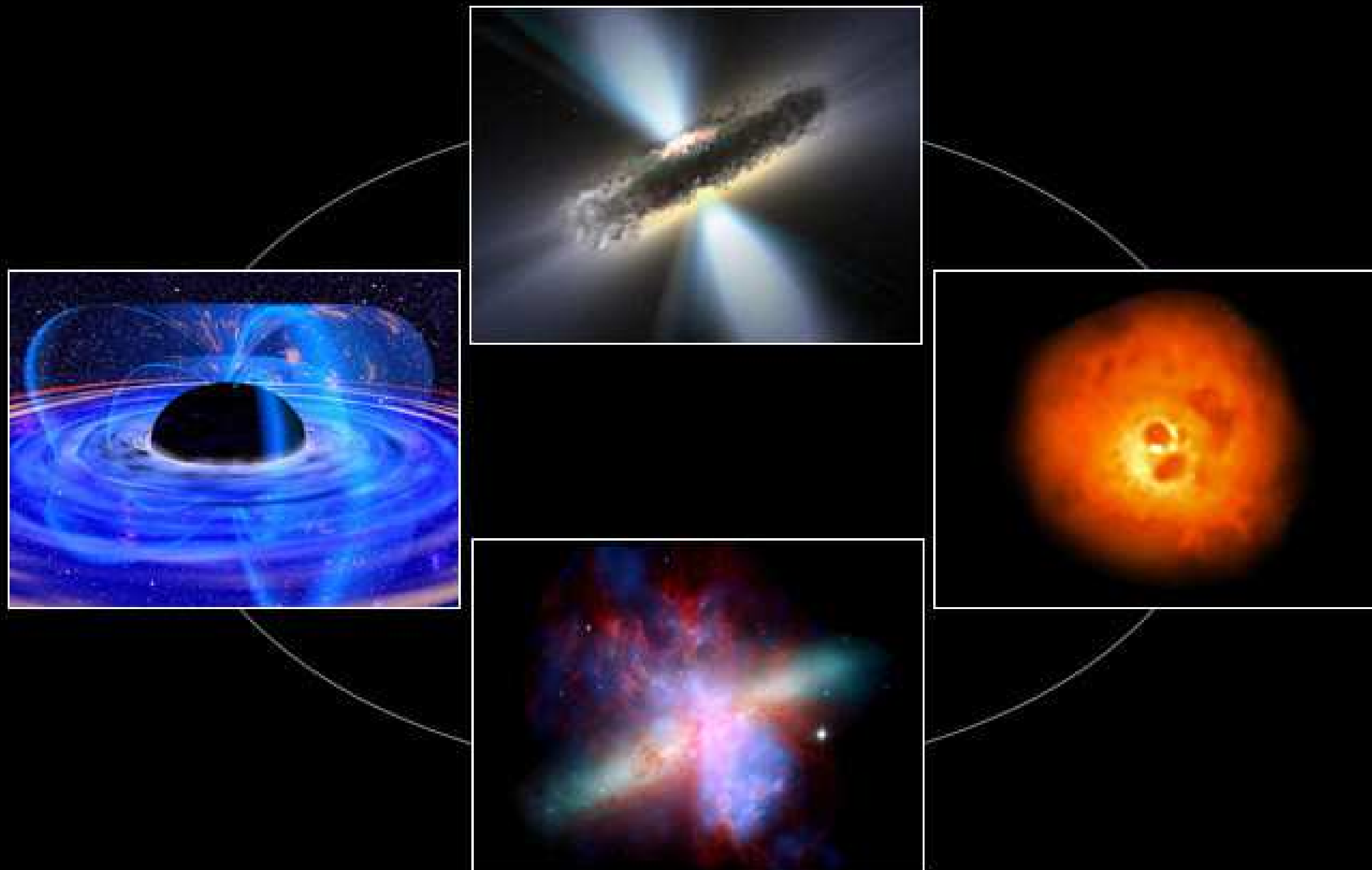
European Space Agency New Vision (28 November 2013):

"The **X-ray observations of the hot and energetic Universe** and the search for gravitational waves will be the focus of ESA's next two *large* science missions."

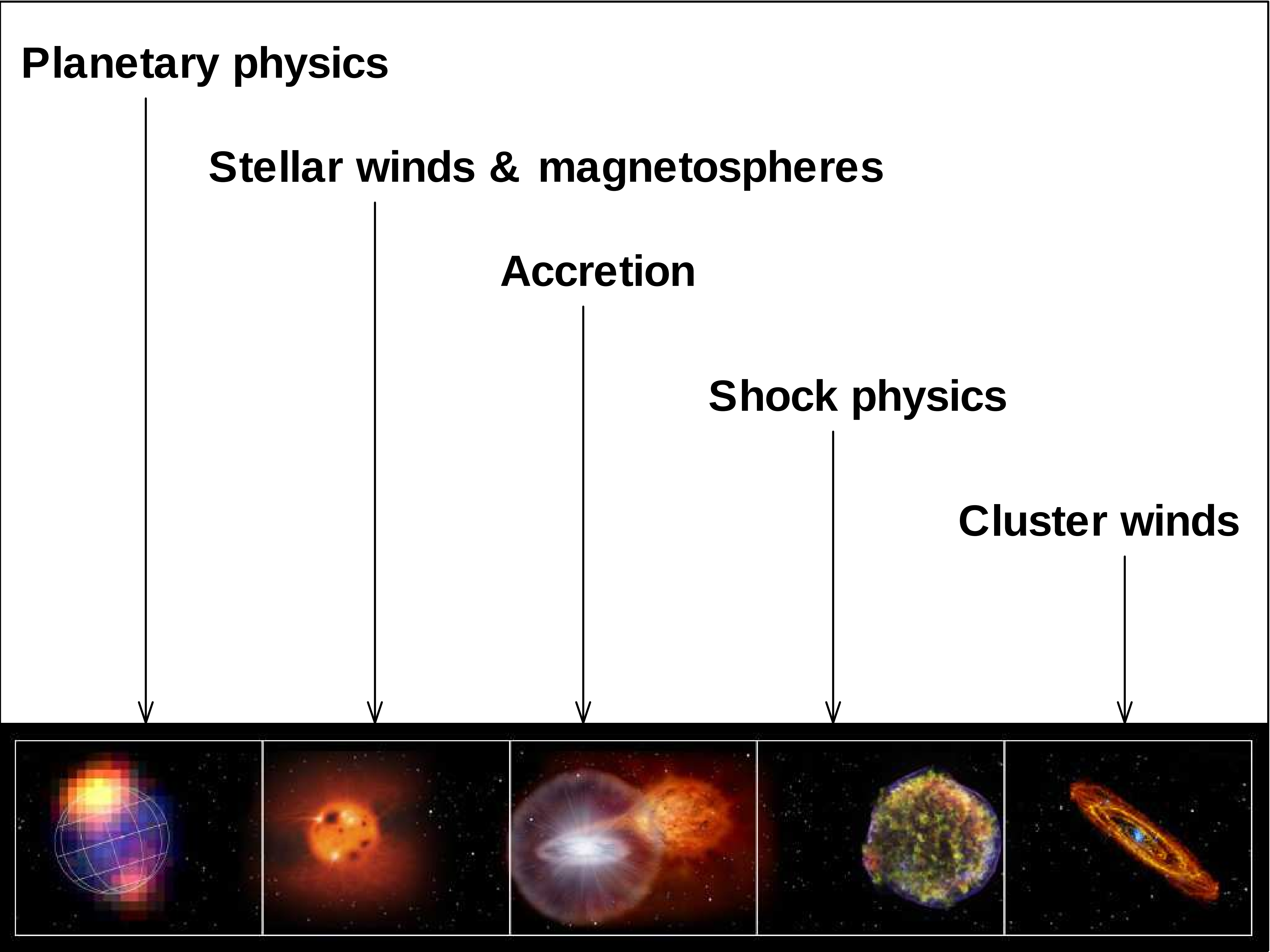
- 2028: X-ray telescope **ATHENA**

  approved budget 1 billion Euro (fixed 2013)

Feedback: stars ←→ galaxies ←→ cosmological structures : X-ray observations



The hot and energetic Universe


Planetary physics
Stellar winds & magnetospheres
Accretion
Shock physics
Cluster winds

New NASA X-ray telescope

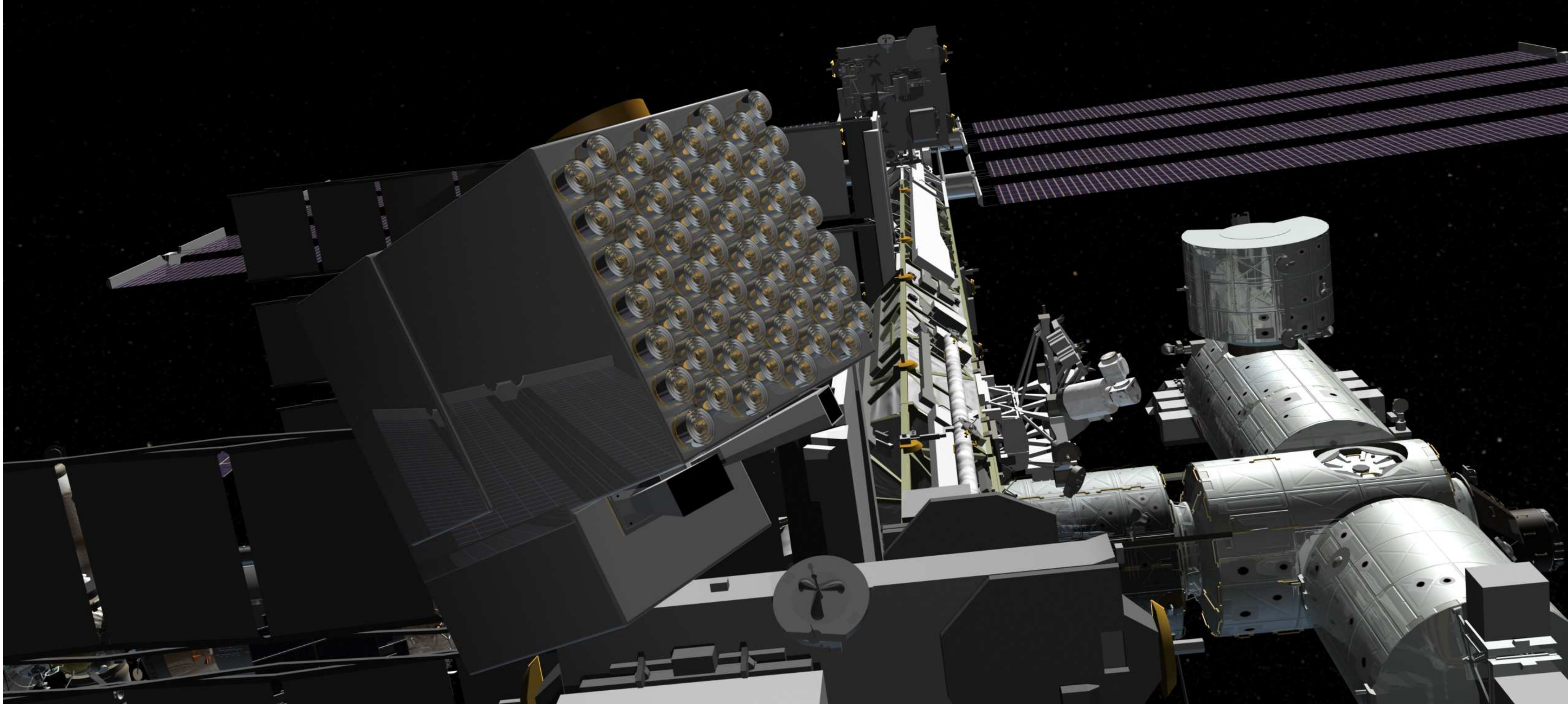
- Array of 56 telescopes mounted on the ISS

Measure X-ray pulsars X-ray light curves

Shape of the light-curve is affected by the gravity

Means to determine the equation of state

- launch on 14 May 2017



Imaging X-ray Polarimetry Explorer (IXPE)

- Improving polarization sensitivity by two orders of magnitude
- Simultaneous spectral, spatial, and temporal measurements,
- Geometry and the emission mechanism of Active Galactic Nuclei and microquasars
- The magnetic field configuration in magnetars
- Particles are accelerated in Pulsar Wind Nebula
- launch in 2020