X-ray Astronomy

Our project uses X-ray data for two things:

1. **Finding galaxy clusters** by the hot X-ray emitting gas that fills the cluster. Low energy "soft" X-rays, with energies of about 1-2 keV. Spatially extended on the scale of the galaxy cluster.

2. **Finding AGN** by the X-rays emitted from the hottest part of the accretion disk around the black hole. Both "soft" and "hard" X-rays, with energies above 2 keV. Since the actual AGN is so small it is unresolved spatially: X-ray point sources.
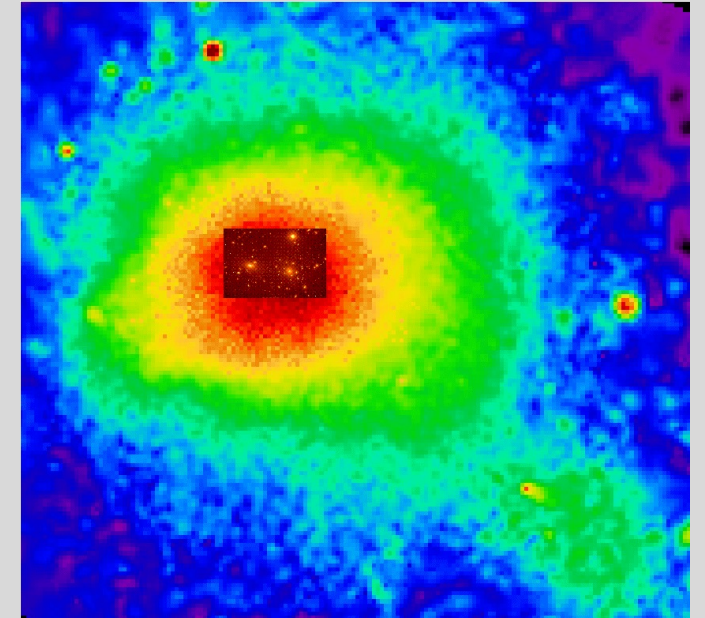
Coma cluster in soft X-rays

AGN in hard X-rays

Optical

2-10 keV

X-ray "**hardness**" $= (H - S)/(H + S)$

where
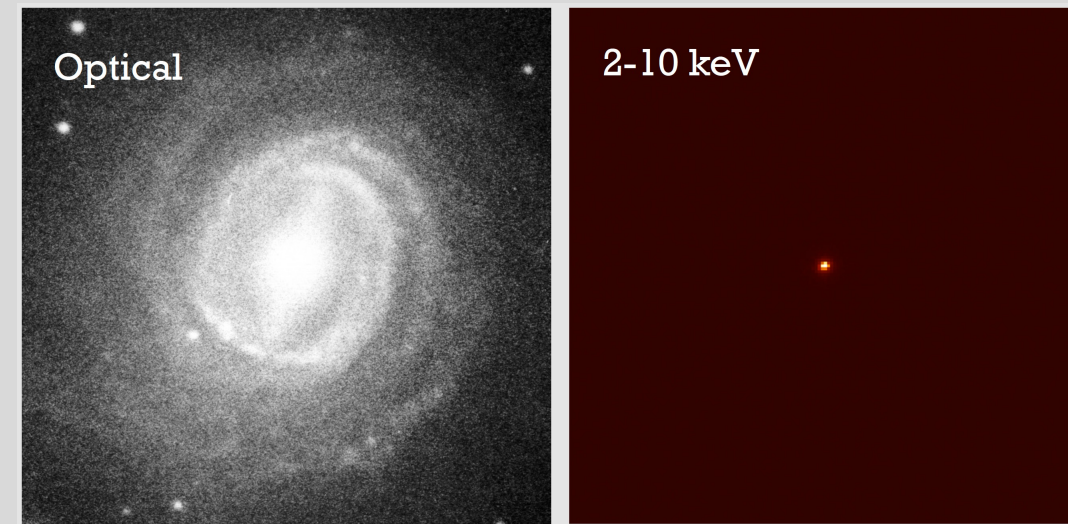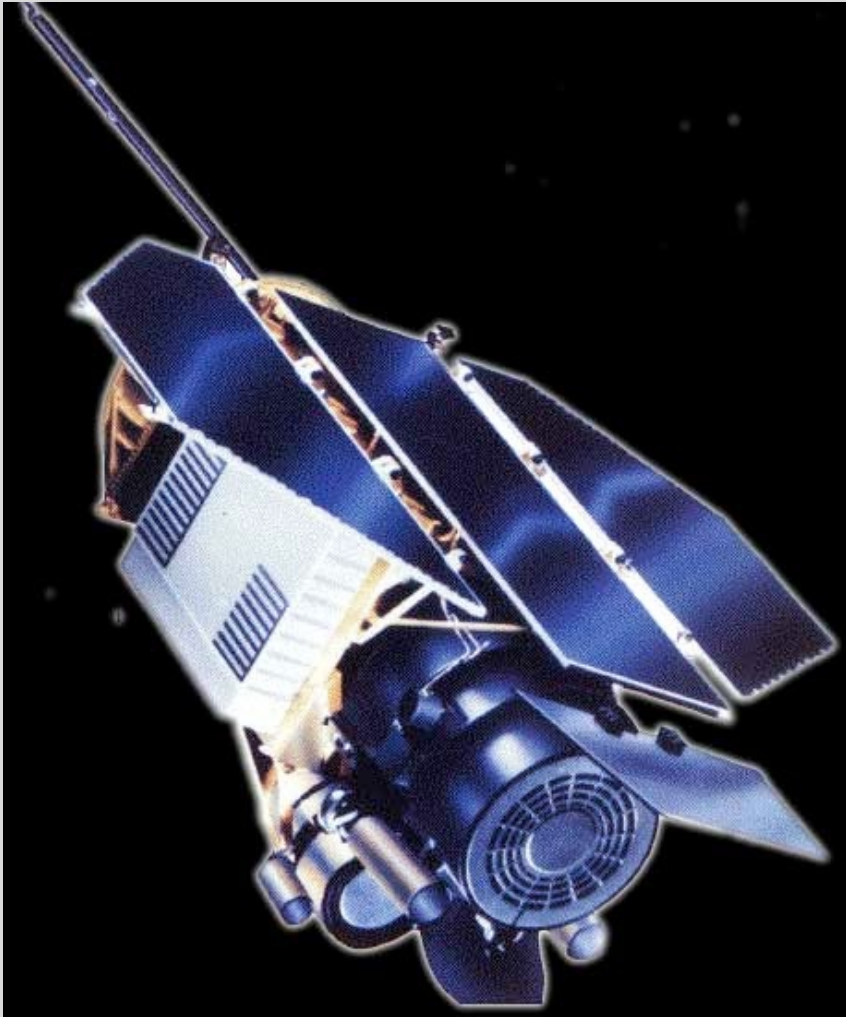- S = soft X-ray flux from 0.5 – 2 keV
- H = hard X-ray flux from 2 – 10 keV

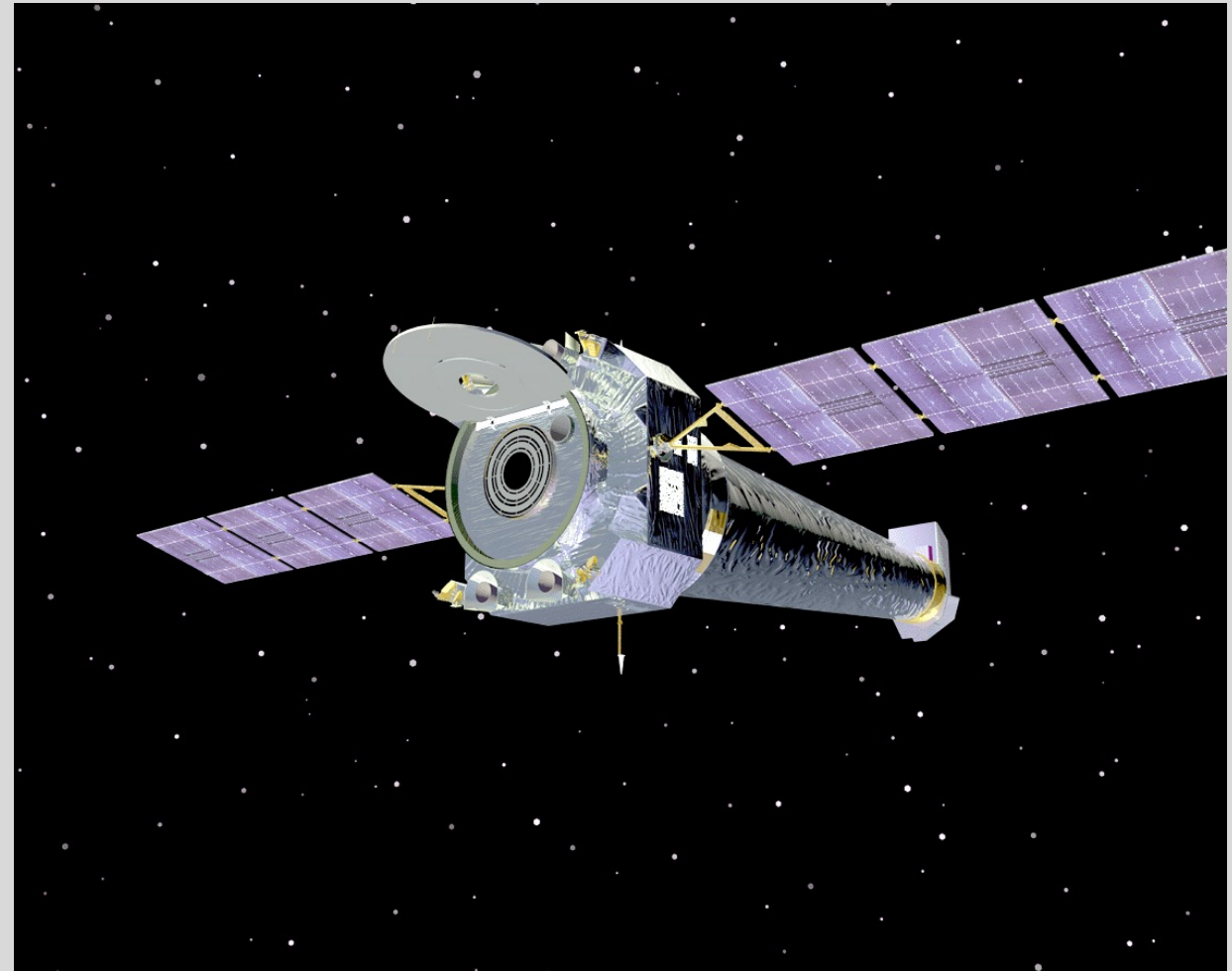essentially a measure of "X-ray color"
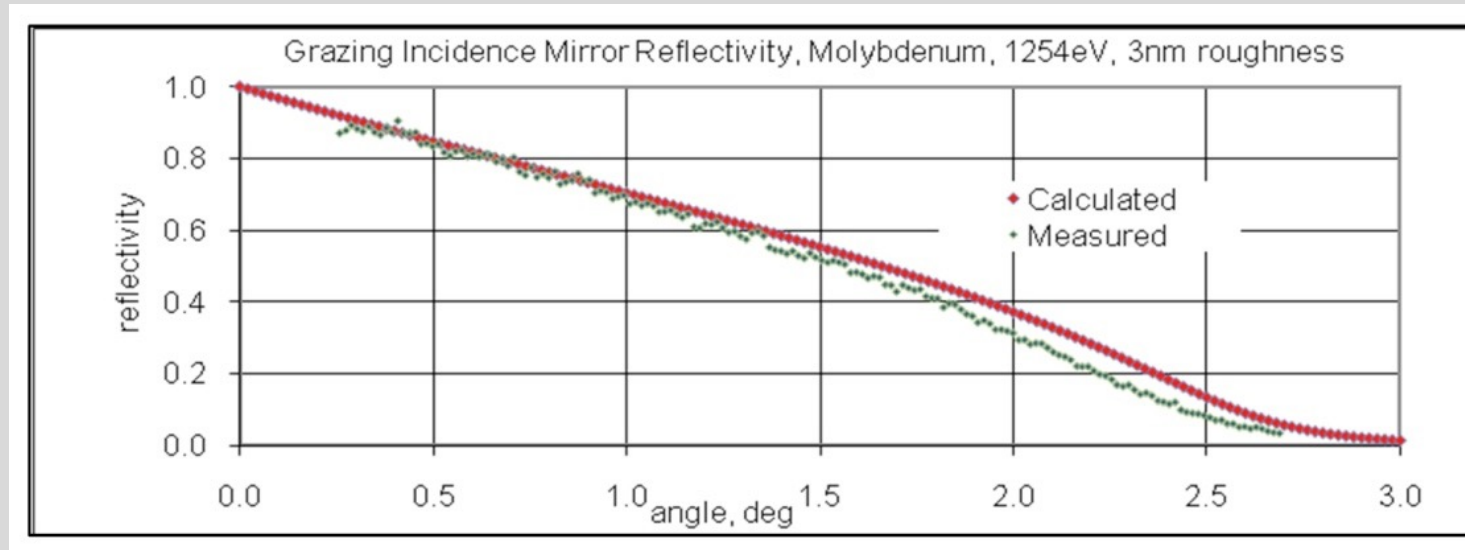
ROSAT – Roentgen Satellite

Joint facility: US, Germany, UK
Operated 1990 – 1999
All-sky survey + pointed observations

Chandra X-ray Observatory

US Mission
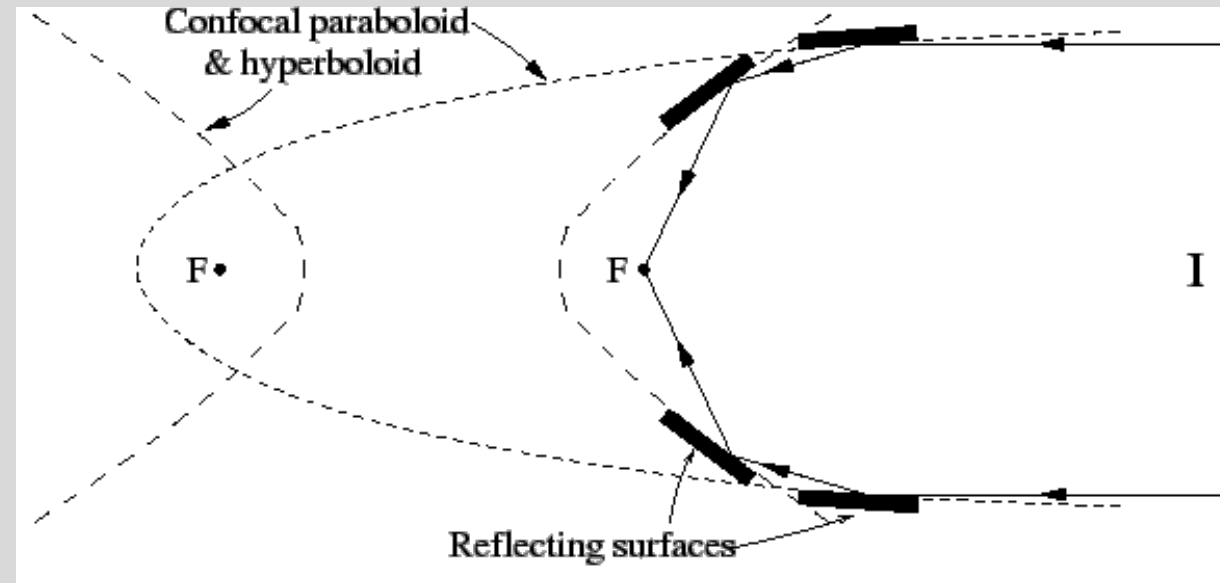Operating 1999 – present
Pointed observations

How do you focus X-rays?

Grazing Incidence Mirror Reflectivity, Molybdenum, 1254eV, 3nm roughness
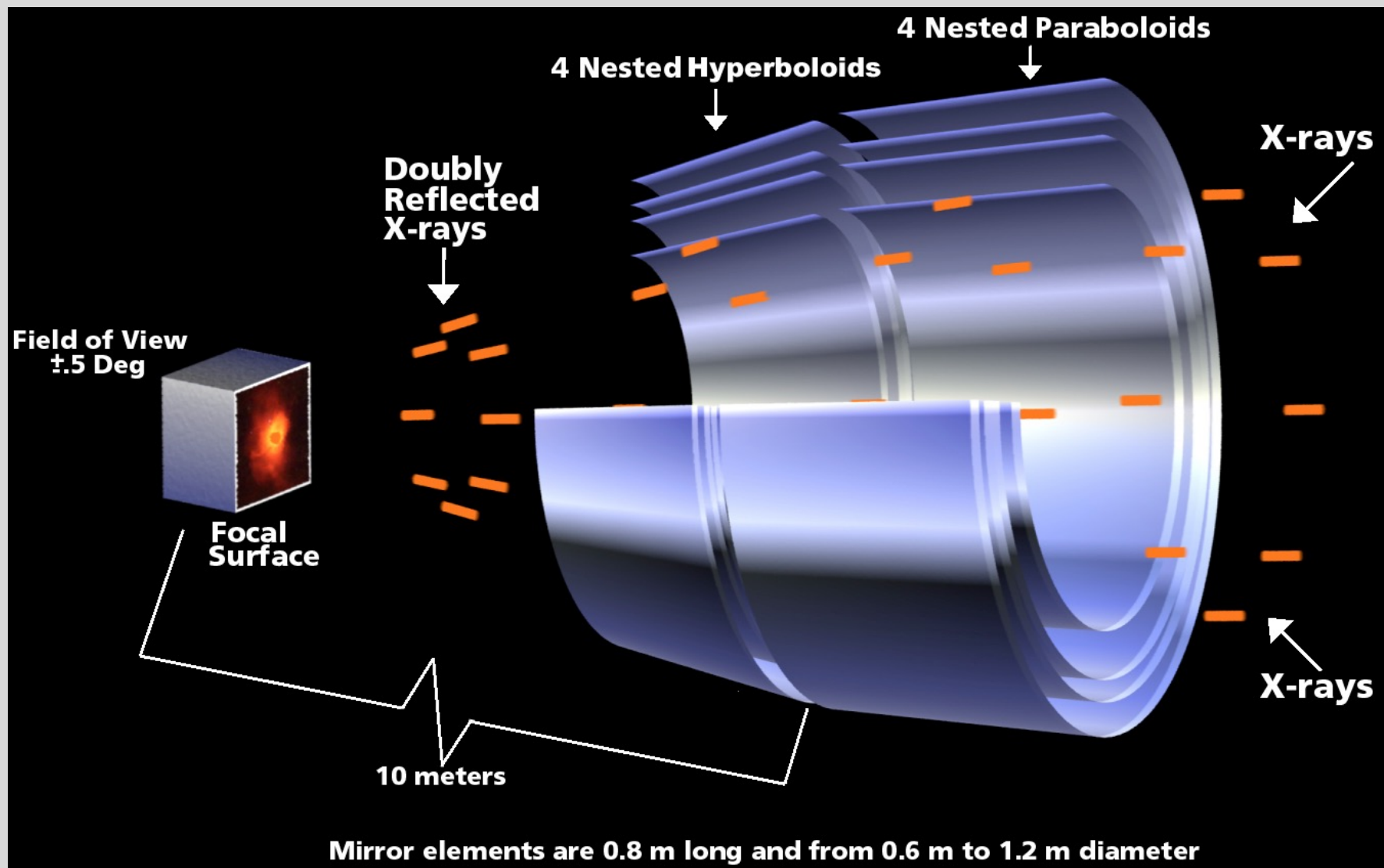
Wolter X-ray telescope

- What is the collecting area (the size) of the telescope?

- How can we improve the collecting area?

Confocal paraboloid & hyperboloid

Reflecting surfaces

4 Nested Paraboloids

4 Nested Hyperboloids

Doubly Reflected X-rays

X-rays

Field of View ±.5 Deg

Focal Surface

X-rays

10 meters

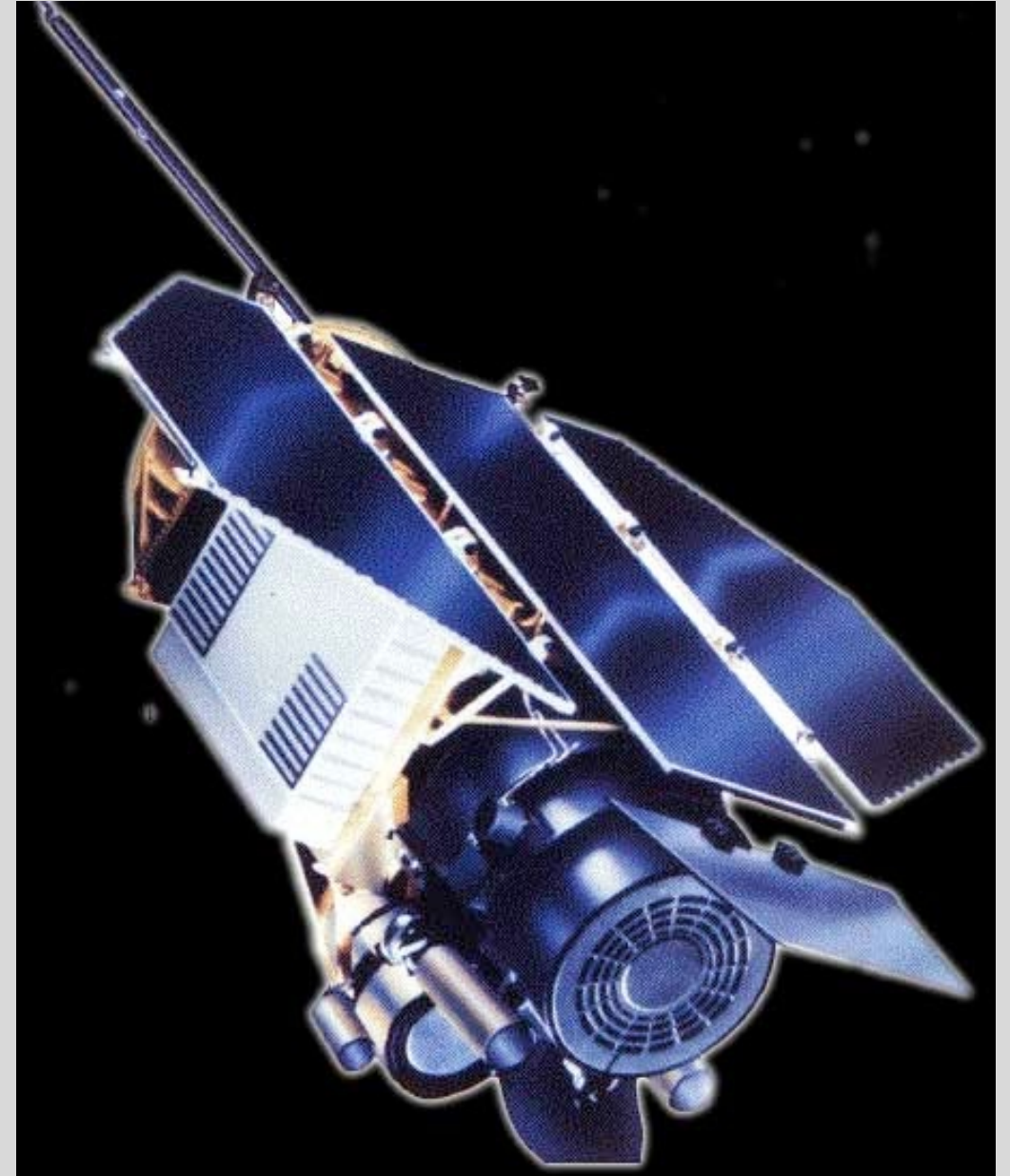**Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter**

ROSAT – Instrumentation

Position Sensitive Proportional Counter (PSPC)
- 20" resolution, 2 degree FOV
- Energy range 0.1 – 2.5 keV
- Effective area ~ 240 cm^2 at 1 keV
  (measure of efficiency of collecting photons)
- Conducted all-sky survey
- Also did pointed observations

High Resolution Imager (HRI)
- 5" resolution, 38' FOV
- Effective area ~ 80 cm^2 at 1 keV
- Pointed observations

Chandra – Instrumentation

Advanced CCD Imaging Spectrometer (ACIS)
- Imaging: 2" spatial resolution, ten 8'x8' CCDs
- Moderate resolution spectroscopy
- Energy range 0.4 – 10 keV
- Effective area ~ 600 cm^2 at 1 keV
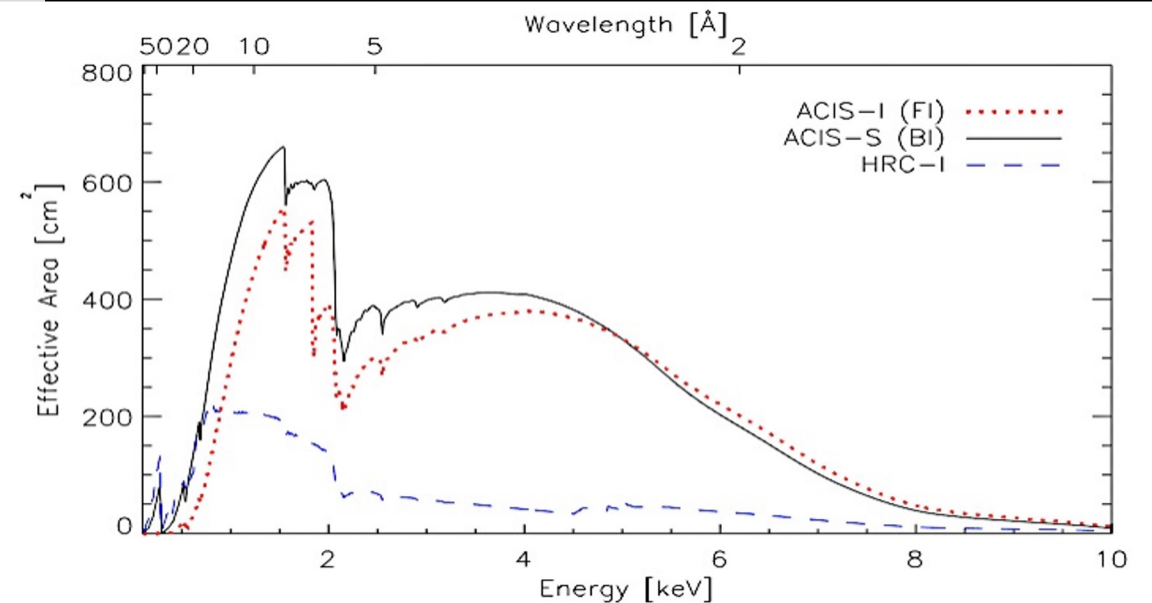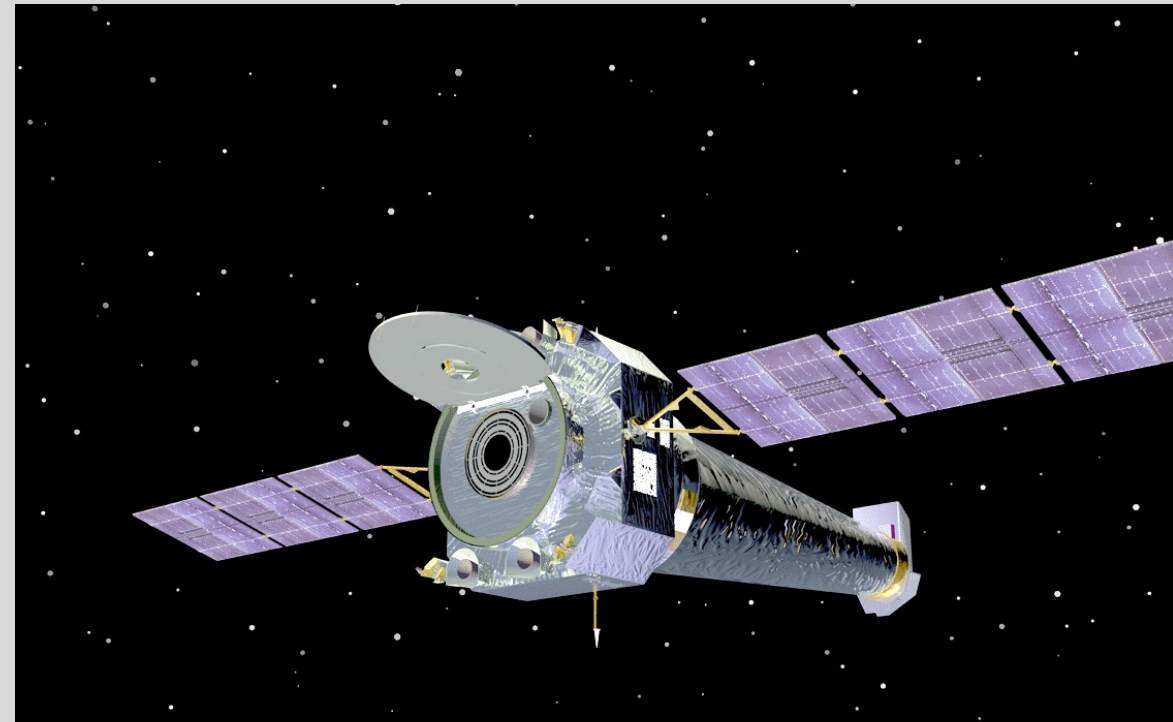 *(measure of efficiency of collecting photons)*

High Resolution Camera (HRC)
- 0.4" resolution, 30' FOV
- Effective area ~ 200 cm^2 at 1 keV

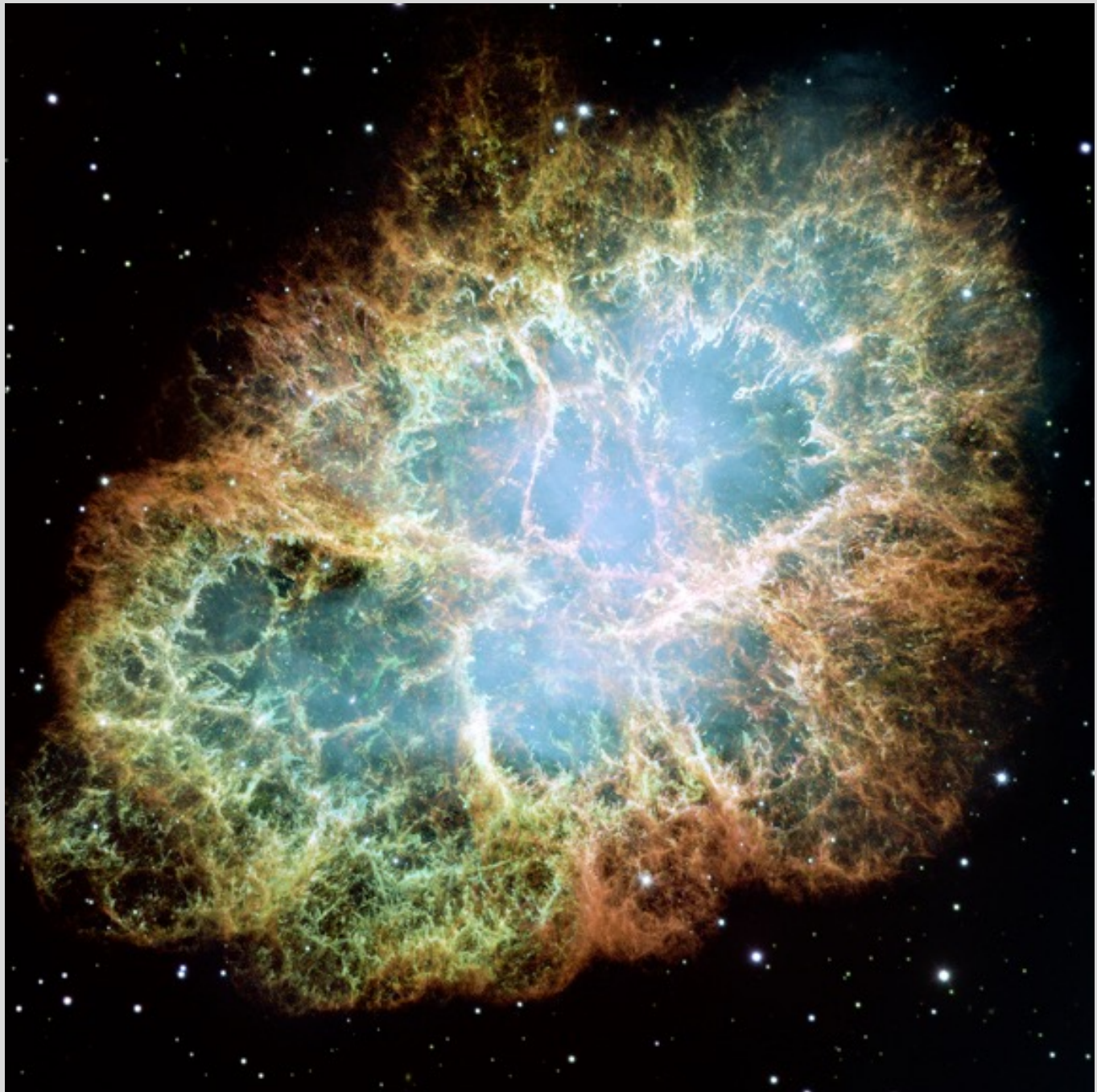***High Energy Transmission Grating (HETG)***
- E/ΔE = 1000
- 0.4 – 10 keV

Low Energy Transmission Grating (LETG)
- Optimized for low energy (0.08-0.2 keV) spectroscopy
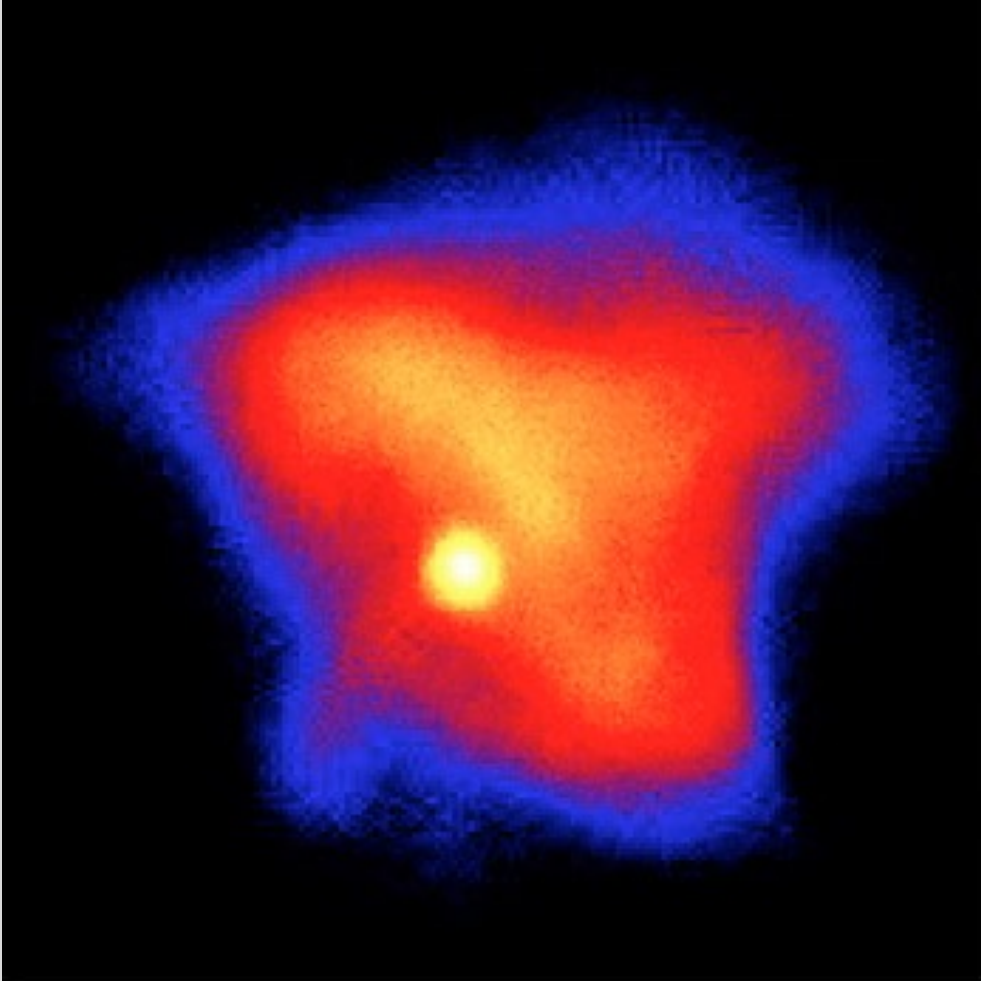
ROSAT vs Chandra:
The Crab Nebula

Optical image

ROSAT vs Chandra:
The Crab Nebula

Crab Nebula, Rosat

Crab Nebula, Chandra

The Sloan Digital Sky Survey (skyserver.sdss.org)

Dedicated 2.5m telescope at Apache Point, NM
Main Survey ("Legacy") operated 2000 – 2008, through Data Release 7 (DR7)
Additional projects since then: SEGUE, BOSS, APOGEE, MARVELS, MANGA (now in DR18)

Imaging:

- Multiband *ugriz*, median seeing ~ 1.3"
- 54s exposure time by scanning gives g_{lim} = 22.2
- ~ 1% photometric uncertainty
- 14,500 square degrees
- 208M galaxies, 260M stars

Fiber spectroscopy:

- R ~ 2000 spectra from 3800 – 9200 Å
- Redshift accuracy ~ 30 km/s
- Galaxies (r<17.8) and Quasars (i<19.1 or 20.2)
- ~ 2.4M galaxy spectra, 0.5M quasar spectra, 0.85M stellar spectra

SDSS Main Survey Data Products: skyserver.sdss.org

Calibrated Images and Spectra:
- Quick look format
- Reduced fits files

Data Products (Imaging):
- Magnitudes, colors
- For galaxies: size, structural information, "photometric redshifts"

Data Products (Spectra):
- Redshift/velocity
- Emission/Absorption Line measurements
- Spectral classification

Catalogs, for example:
- Luminous Red Galaxies
- Quasar catalog
- White dwarf catalog
- Moving objects