X-ray and Gamma Ray Astronomy of Comets and Asteroids

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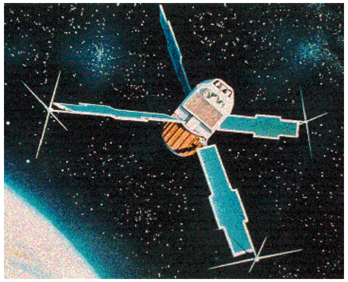
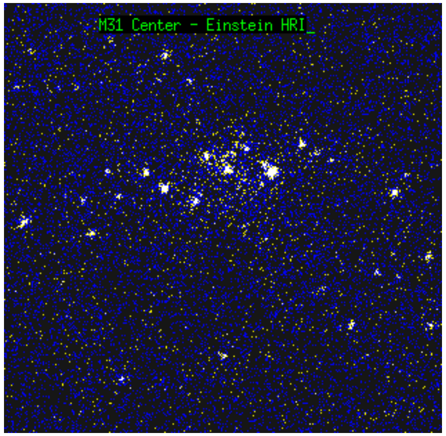
X-ray Astronomy History

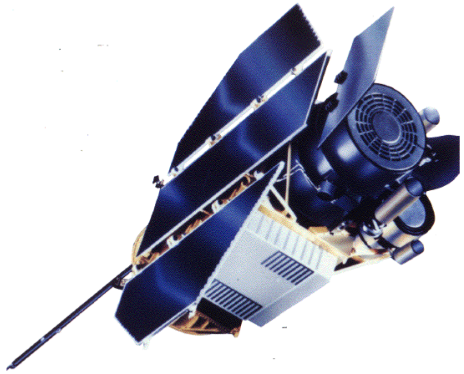


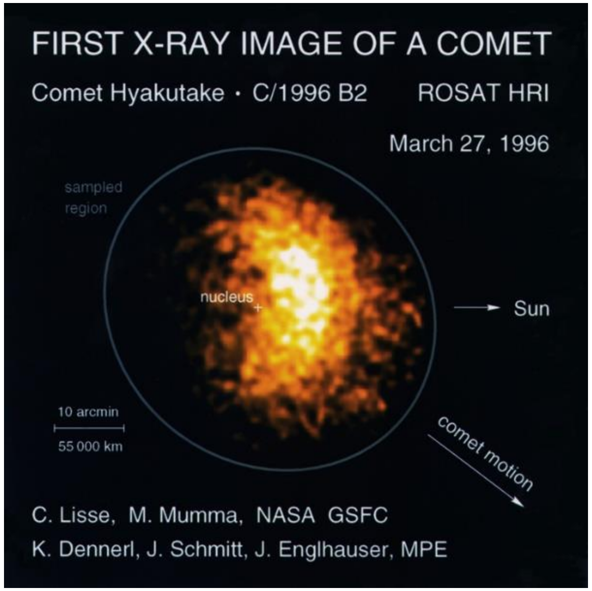
- Dozens of missions since the 1960's involved X-ray detectors
- The first dedicated telescope was Uhuru which was launched in 1970. Consisted of two proportionality counters at the end of a viewing pipe (2-20 keV)
- The first X-ray imagining satellite was Einstein (1978).
  - Introduced grazing mirrors
  - Imaging proportional counter
  - High resolution imager
  - Solid state spectrometer
  - Crystal spectrometer



Cometary X-rays

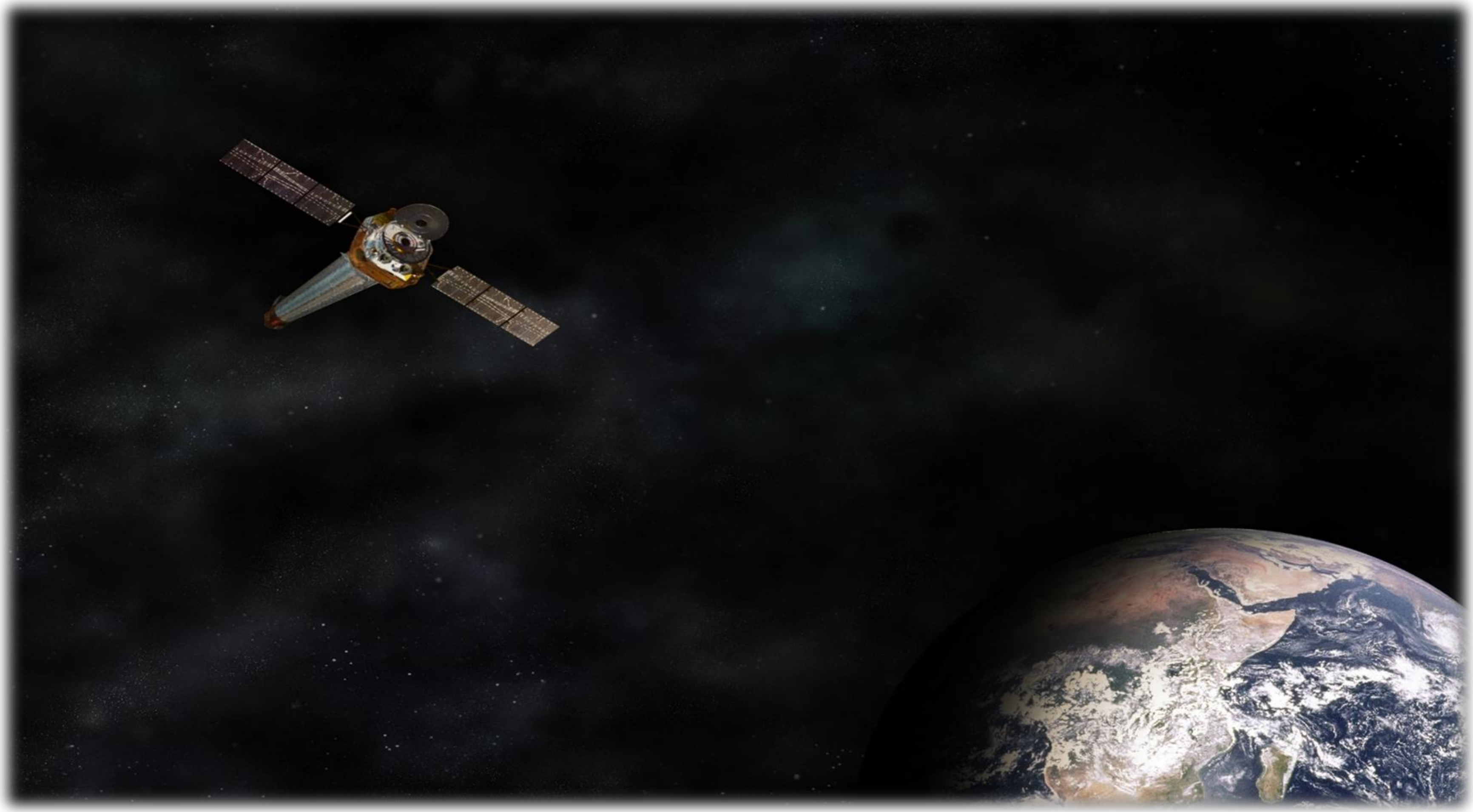
- First satellite to detect was ROSAT (1990)
  - High resolution imager at 0.1-2.5 keV range with 2 arcsecond resolution
  - Proportional counter
  - Wide field camera for UV light
- The comet Hyakutake
  - 100x more luminous than predicted (~10^15 ergs/sec)
  - 3rd brightest X-ray source in the solar system
  - Varied with time
  - Crescent shaped distribution

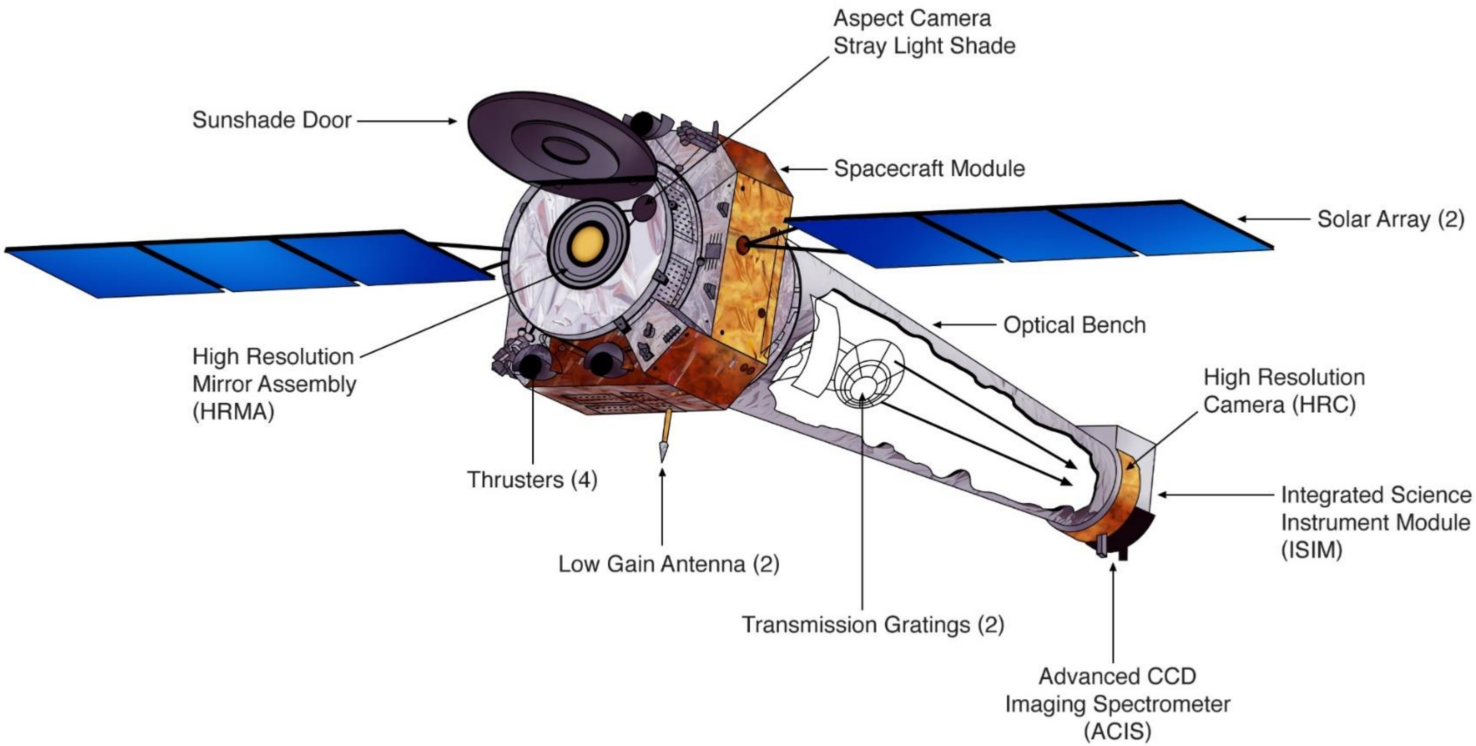




A lot of debate on what caused these features (Bremsstrahlung, K-shell ionization, SWCX, etc)

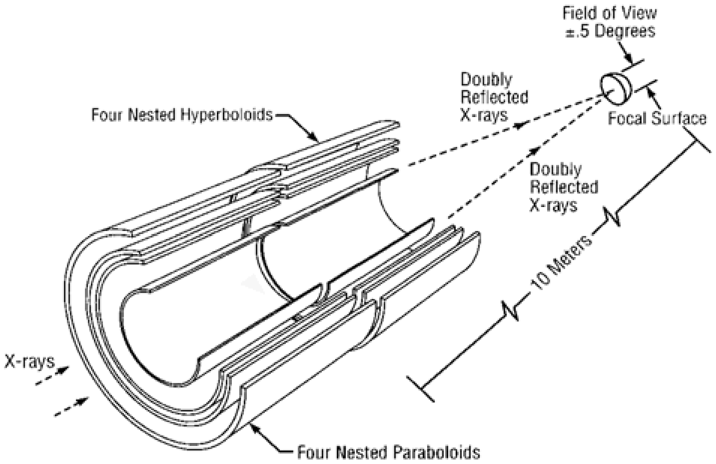
Chandra



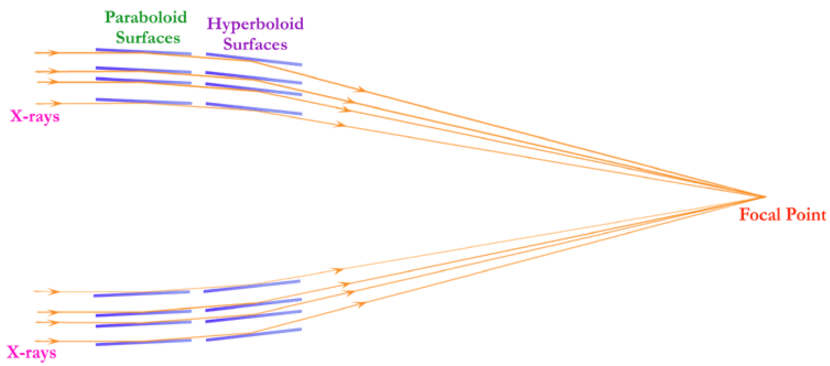


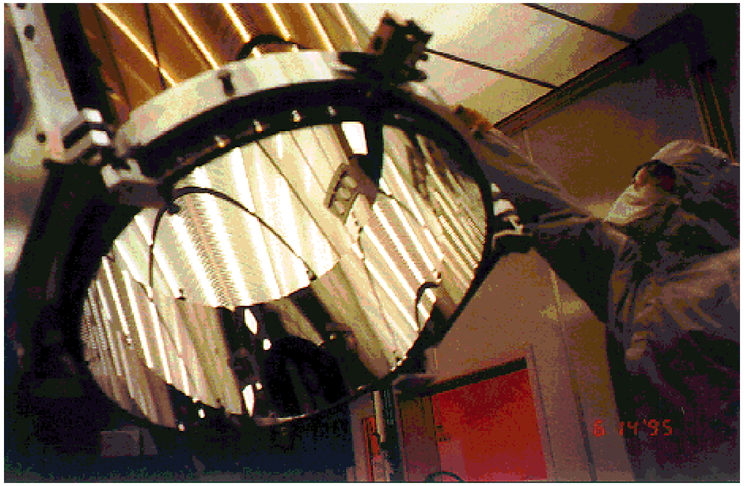
The most advanced X-ray telescope in use today
Almost 14 meters in length
Operates in the 0.06-10 keV range
Highly eccentric 64 hour orbit for long exposures

Chandra's mirrors



- Two sets of four nested mirrors
- Deflects incoming x-rays about 1 degree for each mirror
- Polished to within a few atoms thickness
- Iridium coated for deflection purposes

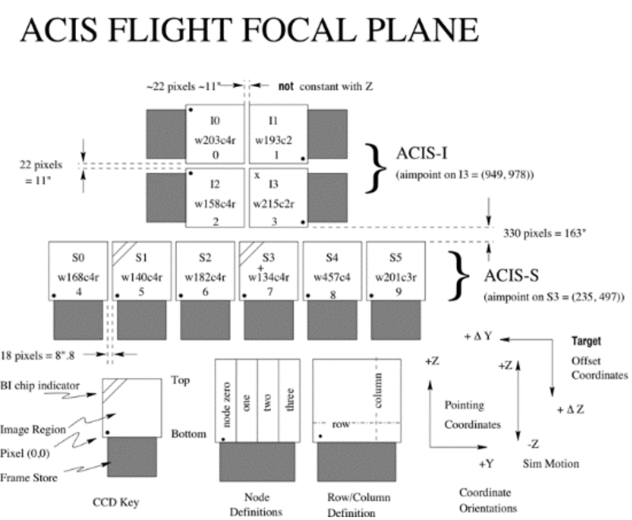


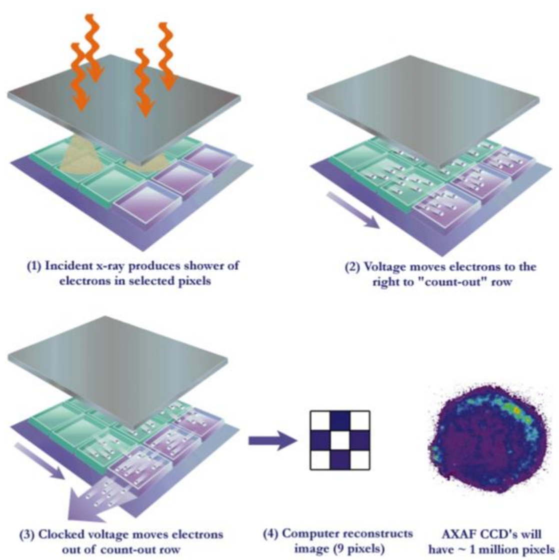


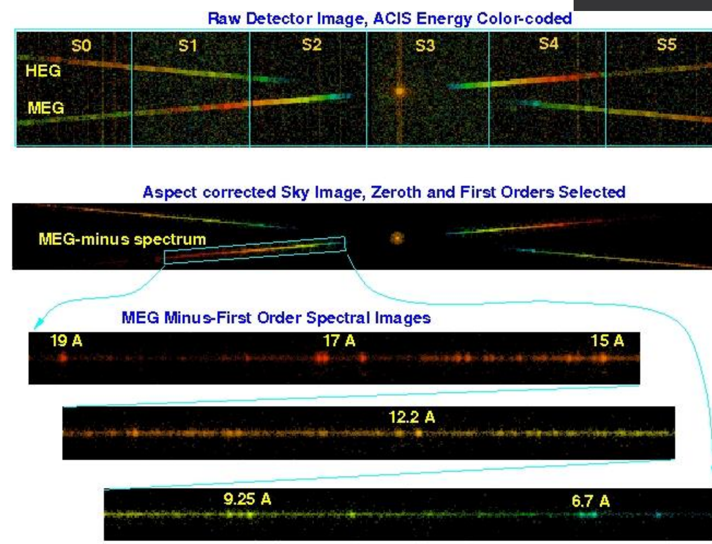
Advanced Imaging CCD Spectrometer (ACIS)

Two sets of detectors. A group of four CCD's for imaging and a row of six CCD's for imaging and spectroscopy.

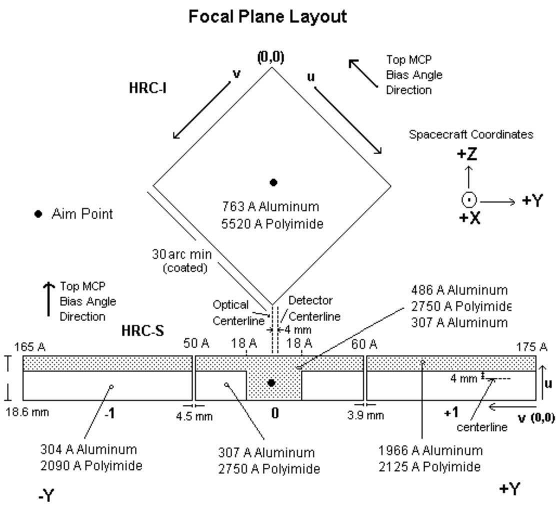
- Each CCD has 1024x1024 pixels
- Collected electrons are passed down the line to a serial readout

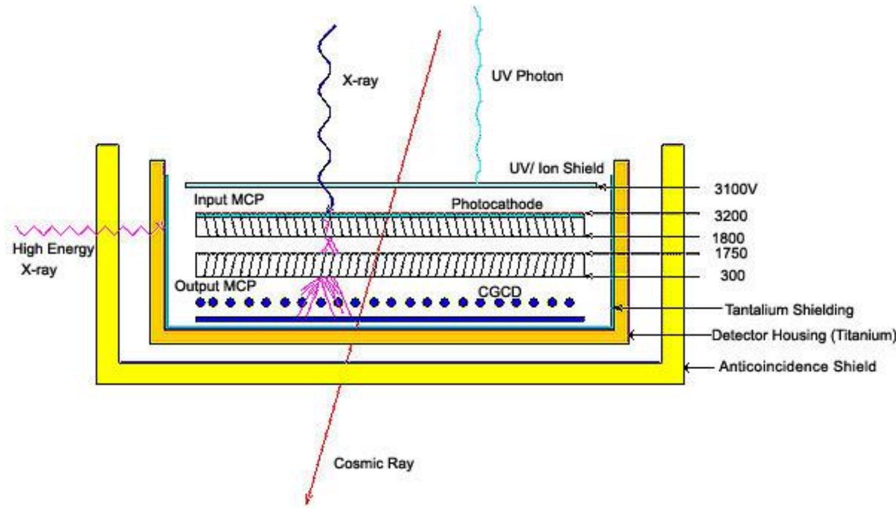






High Resolution Camera (HRC)

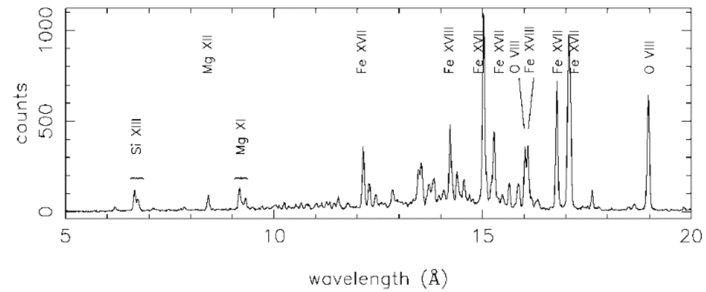




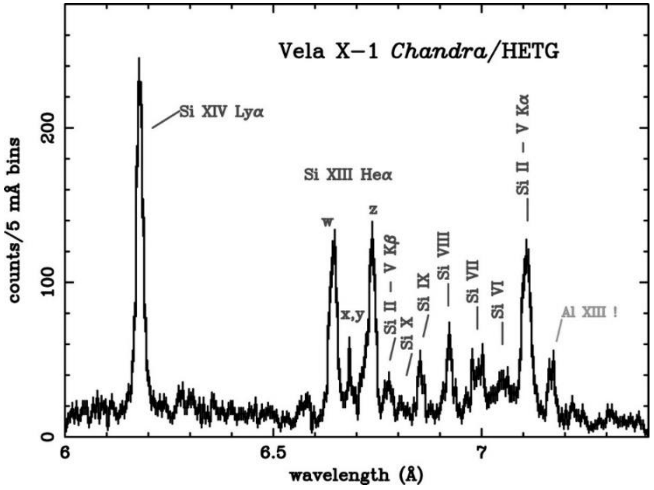
- Two sets of detectors makes up the HRC. Both are microchannel plate detectors (MCP). One for direct imagining, one for spectroscopy with the transmission grating.
  - Input MCP is coated with CsI to enhance photoemission
  - Cascade is dumped onto position sensitive electron detector
  - Cascade effect leaves a distinct physical distribution for X-rays
- Imager has largest FOV of 30'x30' and energy range of 0.06-10 keV.

Low and High Energy Transmission Gratings

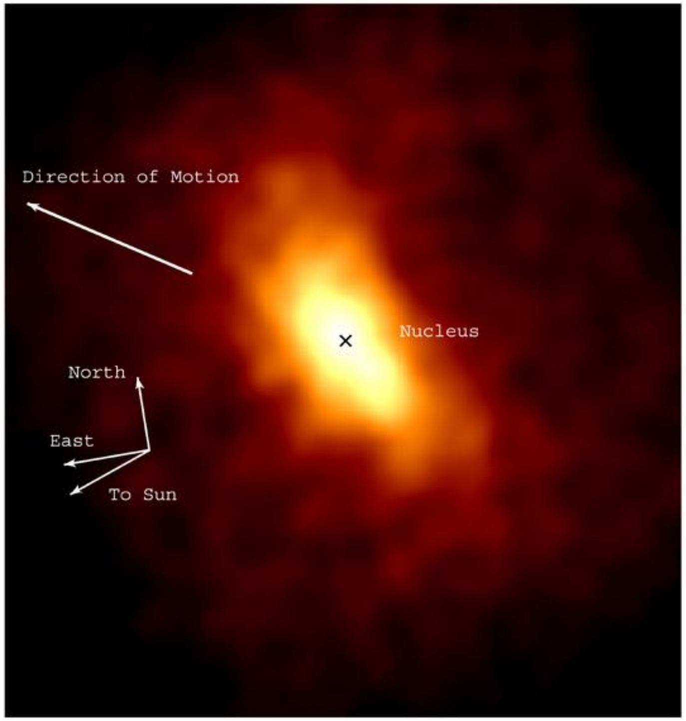
- Low energy transmission grating (LETG)
  - Operates primarily in the 0.07-0.15 keV
  - Can be operated at 0.25-4.13 keV
    but with reduced resolving power
  - Paired with either HRC or ACIS depending
    on source (harder vs. softer spectra)

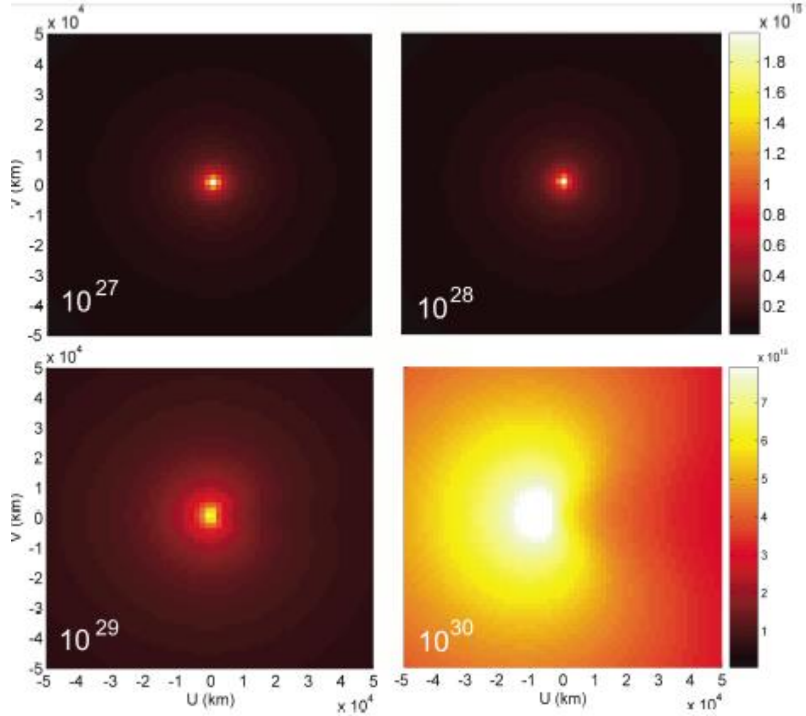


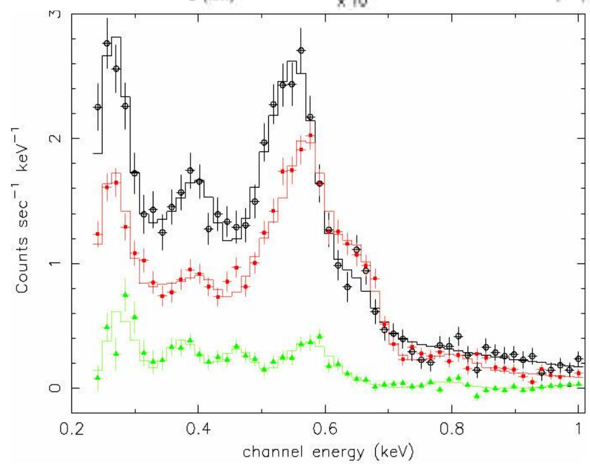
- High energy transmission grating (HETG)
  - Operates in the 0.4-10 keV
  - Can be used to measure Doppler velocities
    of plasmas as low as 50 m/s
  - Most often paired with the ACIS



Chandra's Observations







Chandra clearly showed the temporal, morphological, luminous and spectrum characteristics that settled the debate. Solar wind charge exchange was the only model to explain these features.

Solar wind charge exchange (SWCX)

- Heavy ions in the solar wind exchange charges with neutral targets in the coma.
- Dominated by single charge exchange in the spectrum

  Example: $O^{8+} + H \rightarrow O^{7+^*} + H^+$

  Excited Oxygen will always emit an X-ray on its way to the ground state
- Variety of heavy ions causes a rich spectrum due to the numerous states that can be exchanged. (O^{7+}, O^{6+}, C^{6+}, C^{5+}, N^{6+}, Ne^{8+}, Si^{9+}, Fe^{12+},etc.)
- Emission rate depends on both ion and neutral species

$$P_{sqjn}(\boldsymbol{r}) = n_{sq}(\boldsymbol{r}) n_n(\boldsymbol{r}) < g > f_{sqj} \sigma_{sqn}(g)$$

- Observed in comets, Mars halo, heliosphere background, etc.
- Can be used to measure the density and composition of the solar wind in difficult to reach locations

X-ray spectroscopy of asteroids

- Very little has been done because their signals are so weak
- Cannot image from earth orbiting satellites
- Must get very close with a detector to gather any useful data
- No atmosphere means no SWCX
- Cannot be used as mobile heliosphere laboratories like comets
- There have only been two missions

Hayabusa and NEAR Shoemaker

The only missions to successfully collect data from asteroids in the X-ray spectrum.

Hayabusa (2003)

- Designed to collect samples
- X-ray spectrometer on the orbiter (CCD based of 0.7-10 keV)
- Detected X-ray fluorescence on the surface

NEAR Shoemaker (1996)

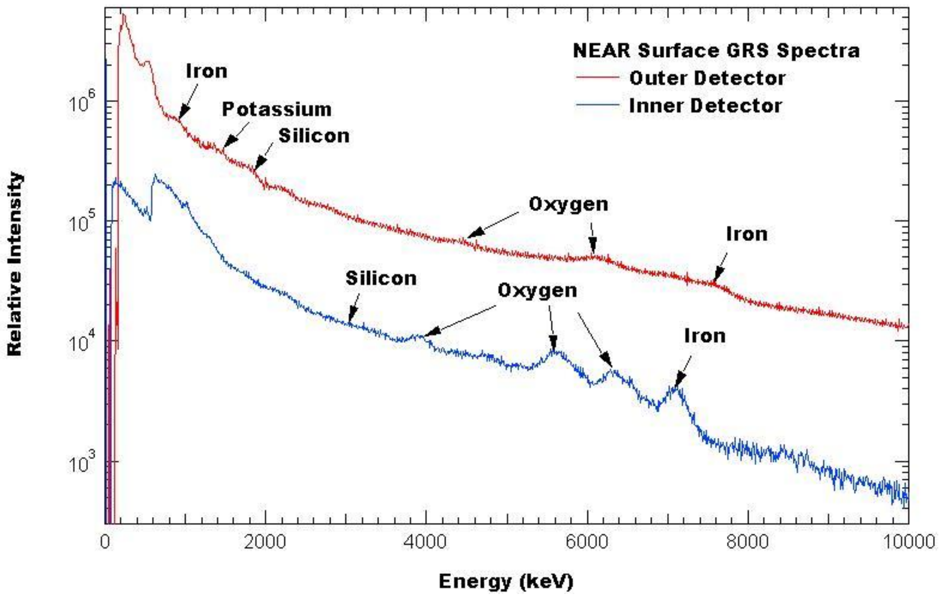
- Designed as an orbiter only
- X-ray spectrometer (Three gas-filled proportional counters of 1-10 keV)
- Orbited Eros for a full year then landed on the surface anyway

Gamma rays of comets and asteroids

Only one mission has taken gamma ray data, NEAR Shoemaker.

- Combination X-ray/gamma ray spectrometer (XGRS)
- Gamma ray detector operated in the 0.3-10 MeV range

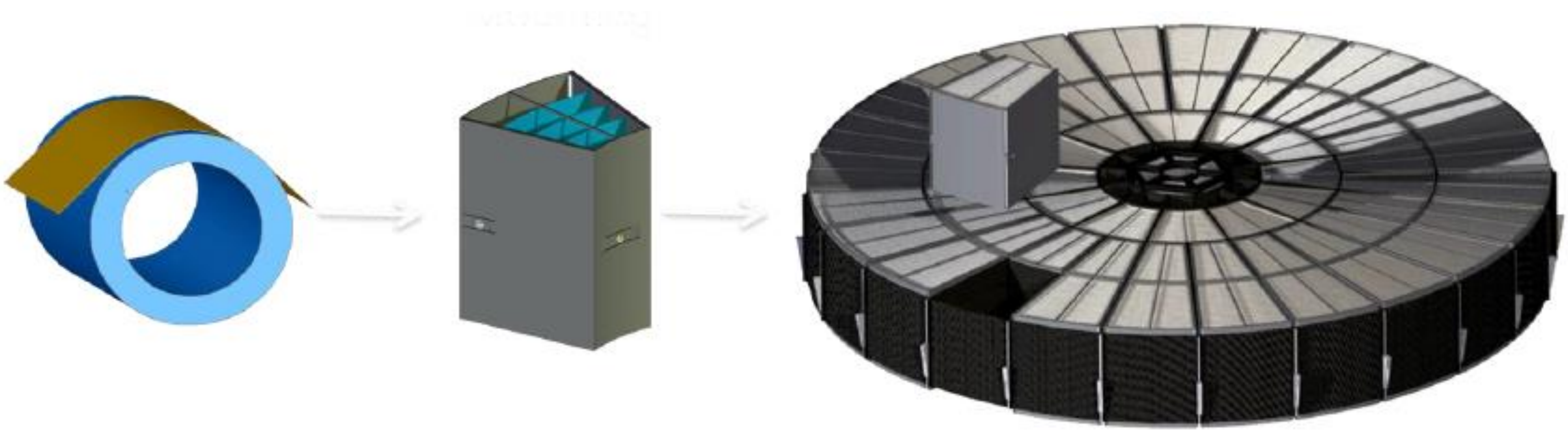
After NEAR's landing on Eros the gamma ray detector took data for 7 days. This data was far better than all of the previous data taken from orbit.



What's next?

The X-ray Surveyor

- Proposed successor to Chandra
- Strong focus on photon collection to improve imaging
  - New mirror assembly to drastically increase photon throughput
  - Build a series of modules using slumped glass
  - Possibly also use adjustable optics and/or differential deposition



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