HOW TO "SEE" X-RAYS

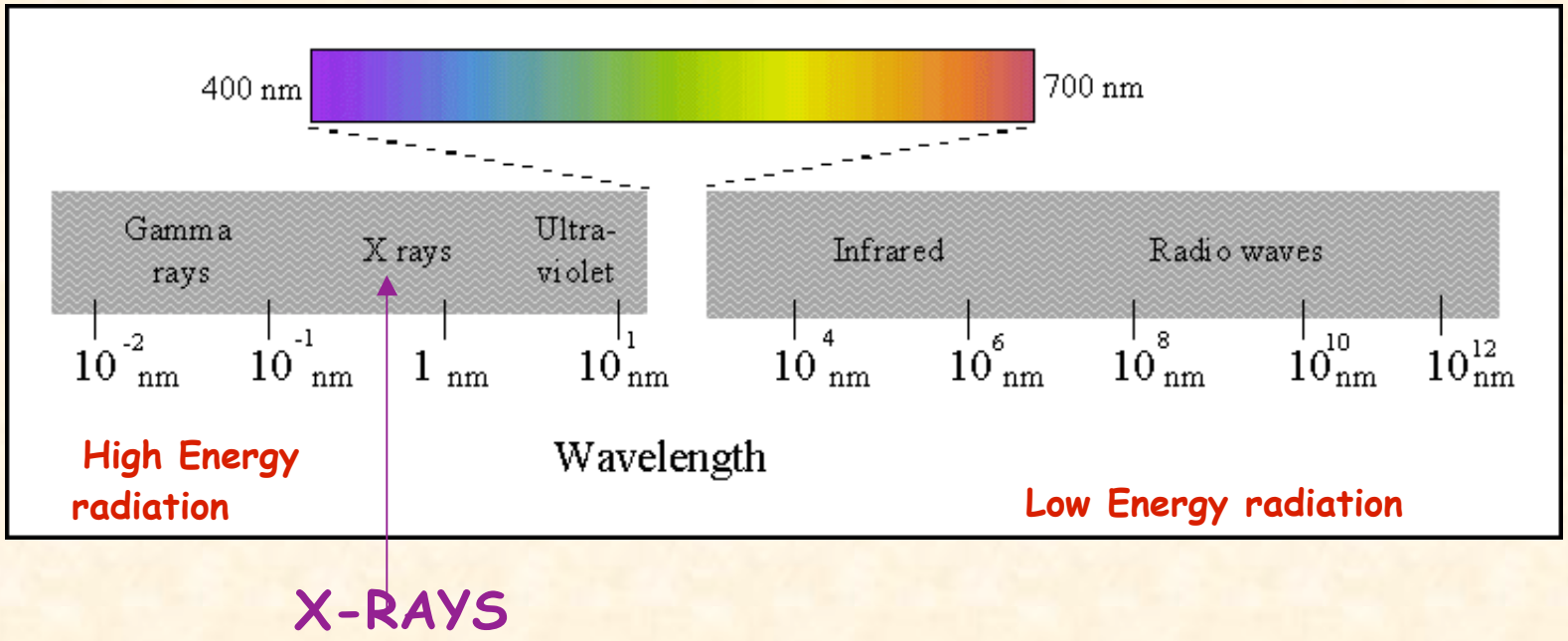
By,
Kimberly Cochrane
Bowie High School
Prince George's County Public Schools, MD

WHAT ARE X-RAYS?

X-rays are ***photons*** that have short wavelengths and high energy.

X-rays from space are created within celestial bodies that are **millions of degrees** in temperature. They are often produced in neutron stars, black holes, and supernovae.

The Electromagnetic Spectrum

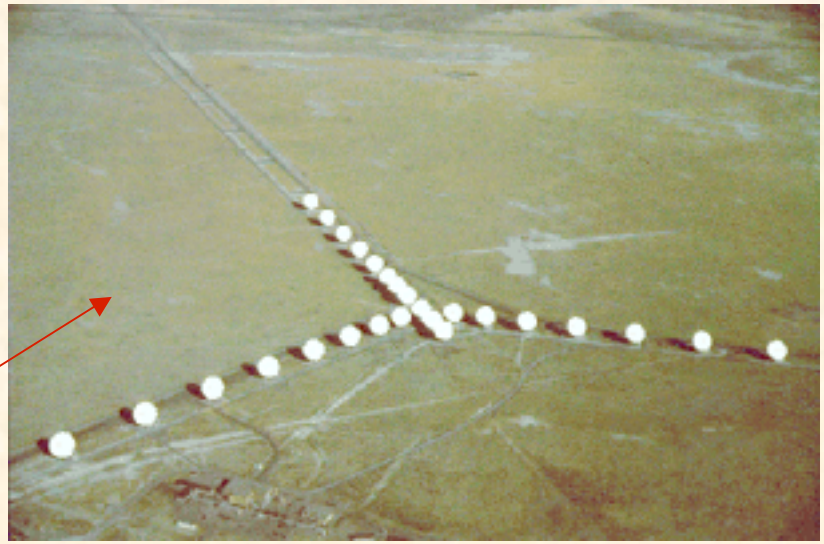


All EM radiation is in the form of **photons**, which have both wave and particle properties. The low energy radio waves have very long wavelengths. The long wavelengths makes capturing radio waves different from capturing other types of waves.

Radio telescopes focus radio waves to a **focal point** using a conductive metal. The telescopes must be very large to capture all of the long radio waves. The long wavelength allows scientists to create clear images.

Notice the size differences of the two telescopes below. The Very Large Array (VLA) contains 27 telescopes in a Y-pattern covering 22 miles!

Radio Telescope



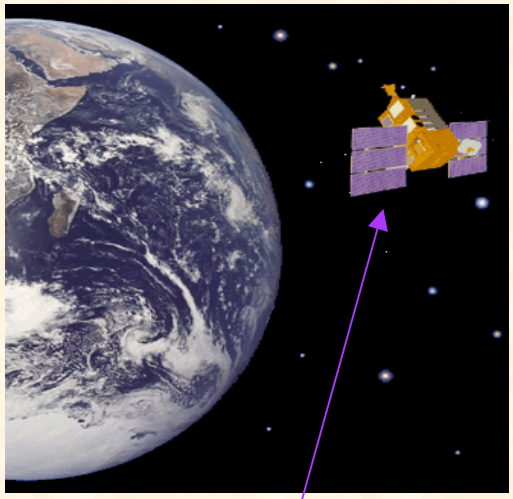
VLA

X-rays are high in energy but have short wavelengths.

X-rays from space interact with the oxygen and nitrogen molecules in the Earth's atmosphere. Due to the interaction, they are absorbed before reaching the surface of the Earth.

Also, due to their short wavelengths they pass right through traditional mirrors used to focus visible (light) waves.

Astronomers must build special detectors to observe X-rays. They place these detectors above the Earth's atmosphere.



The Rossi X-ray Timing Explorer

The X-ray Machine

How does the X-ray machine work?

The X-ray machine works similar to a camera.
However, the camera uses visible light
to make its images and the X-ray machine
uses an X-ray source to make its images.

They both use a film, that has to be developed,
to capture the images.

The high energy particles ...

Since X-rays are very energetic particles, they can be used to see many internal human body structures.

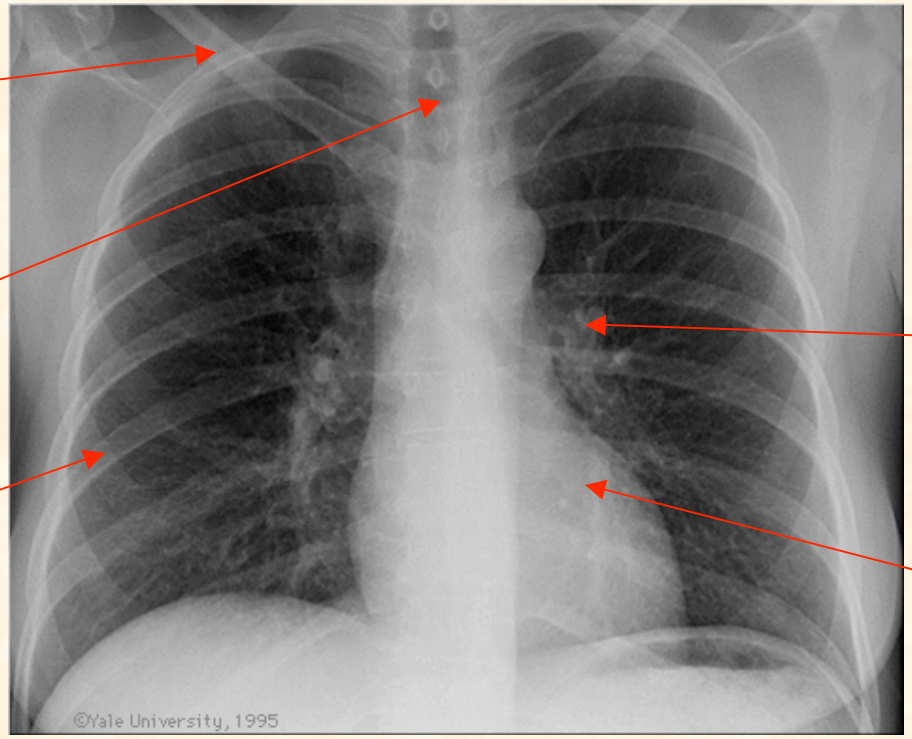
The X-rays are able to penetrate different tissues in varying amounts. The difference in the X-ray's ability to pass through depends on the tissue's density.

As the X-rays encounter the human tissue they have three choices. They may pass through,bounce off, or partially penetrate the tissue. The X-ray film "counts" the number of X-rays that hit it at each position on the film. The image is built up as the number of X-rays that hit the film increases.

The Results

The result of this process is an X-ray image that doctors can use to help diagnose conditions or diseases.

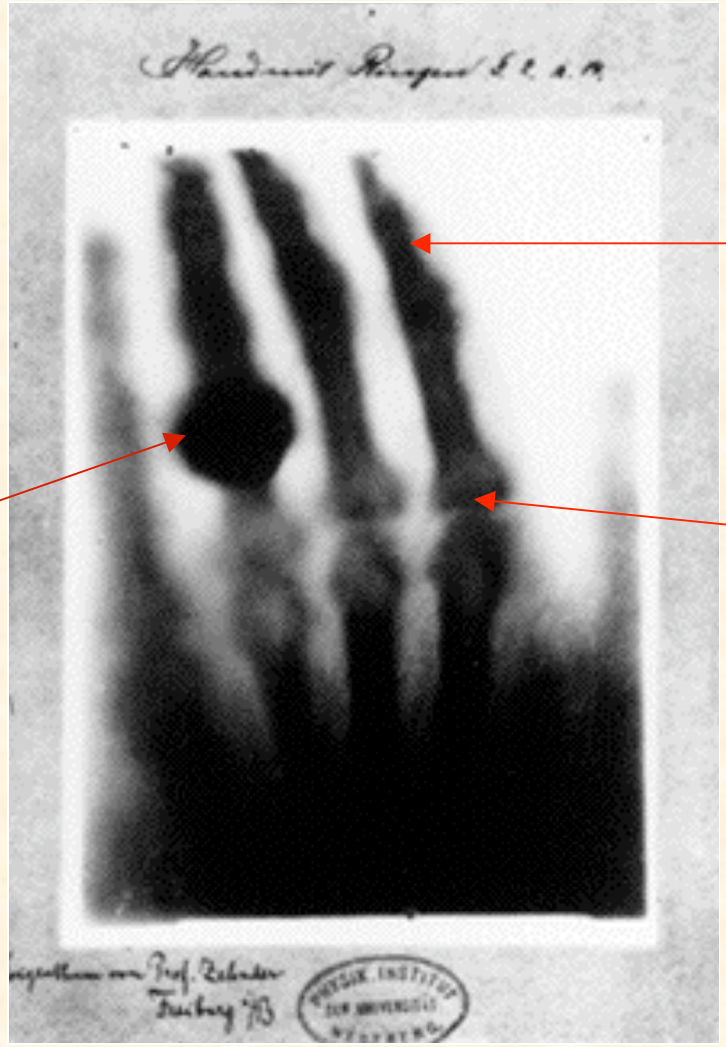
Notice that objects look different due to their different densities and the amount of X-ray radiation that penetrated the tissue.



An X-ray picture of a human chest cavity.

The very first X-ray picture was taken in 1895 by a German Scientist named Wilhelm Conrad Roentegen.

X-ray picture of his wife's hand

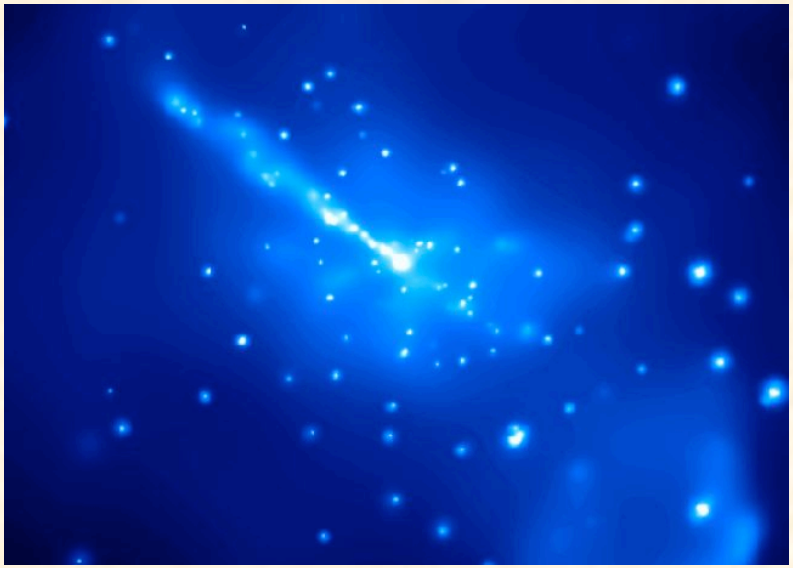


Phalange

His wife's wedding ring

Hinge joint

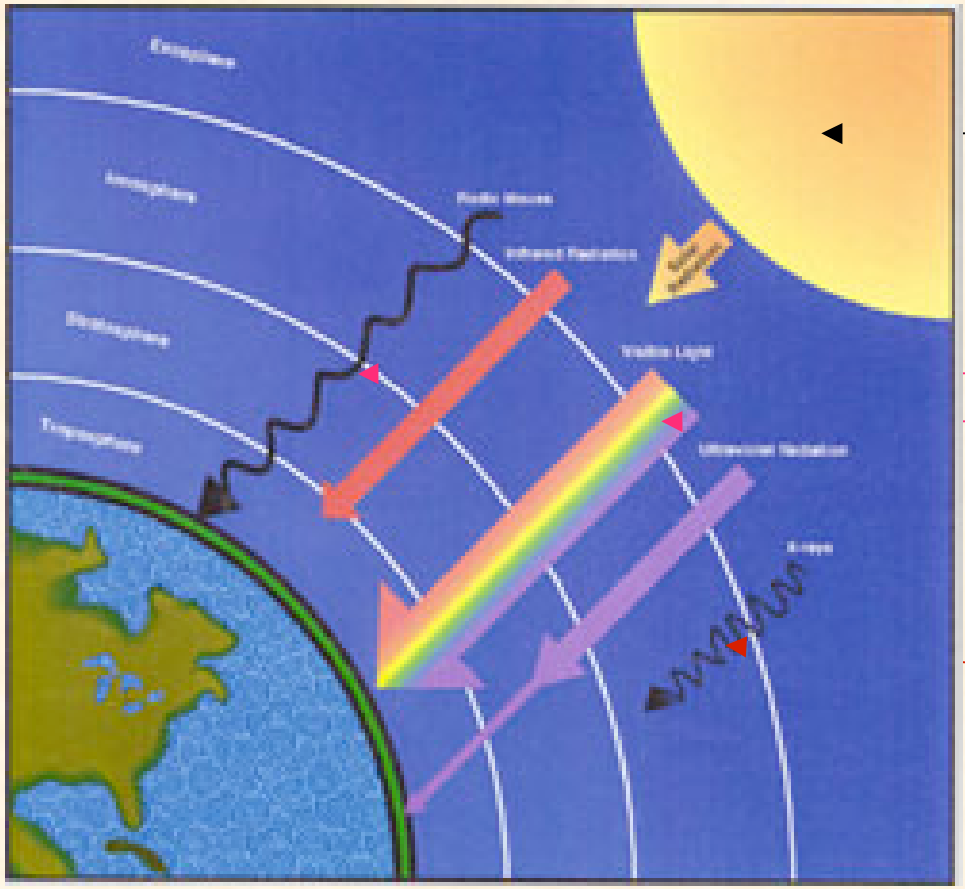
However, the X-ray images that astrophysicists use today are much different from Roentegen's original image. While Roentgen used a source of X-rays and counted up how many passed through an object on its way to the film, astrophysicists collect the X-rays that are generated by high energy processes in objects in space.



An example of an X-ray image from the Chandra X-ray Observatory:

X-ray image of the giant elliptical active galaxy Centaurus A.

Because the Earth's atmosphere prevents the X-rays from hitting the Earth, scientists must get above the atmosphere (in satellites) to view X-rays.



Radiation coming from sun

Radio and visible radiation pass through atmosphere

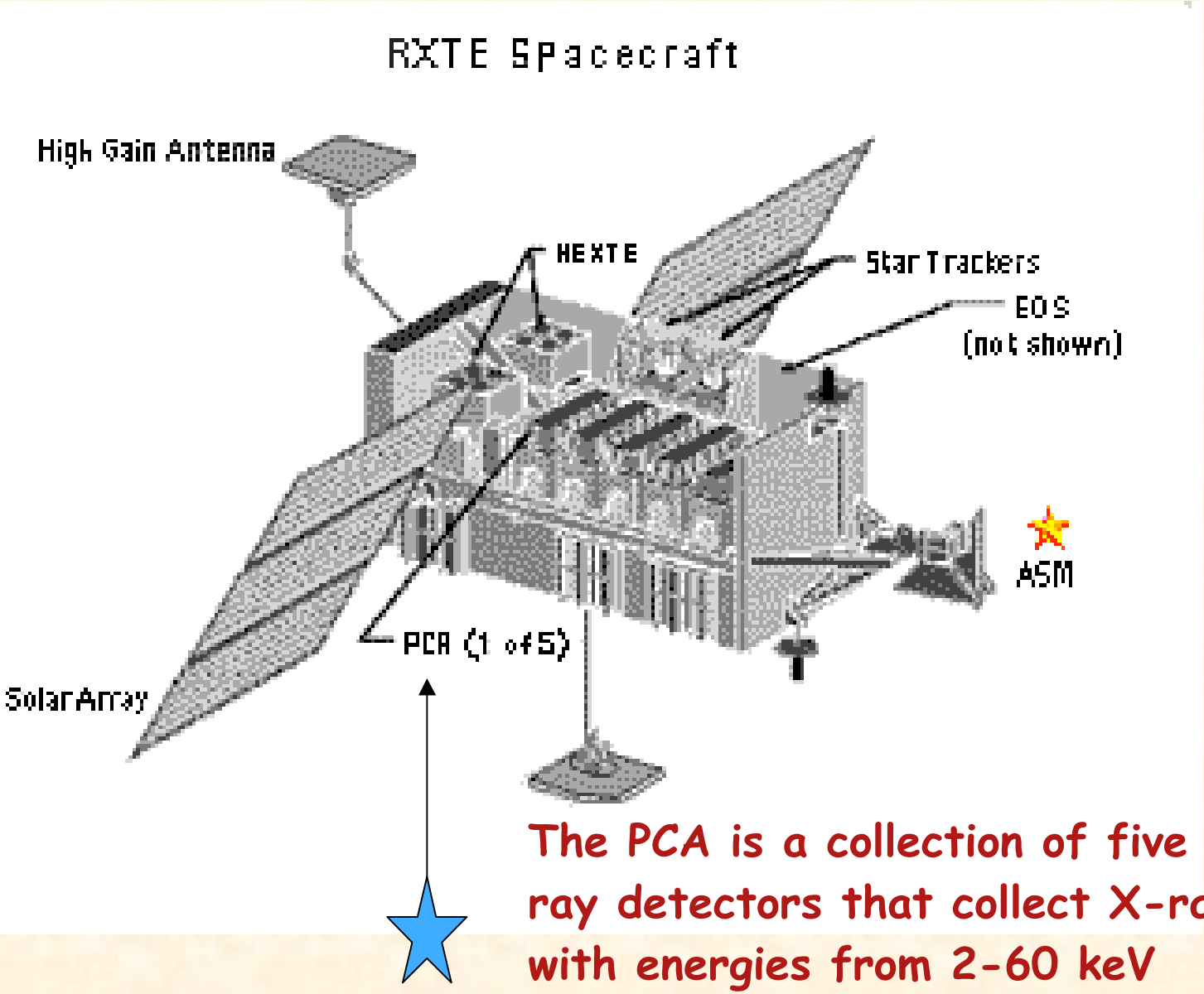
Short wavelengths can not pass through atmosphere. X-rays interaction with nitrogen and oxygen in the upper atmosphere.

There have been many satellites used to observe X-rays. Two of the best that we have today are the the Chandra X-Ray Observatory and RXTE.

Chandra is able to produce images of X-ray emitting celestial bodies. Scientists then assign a color to each position based on the spectral data.

RXTE does not produce images; instead it collects its data as a time series of counts and energy versus time. Therefor, RXTE produces data which is analyzed using light curves (intensity versus time) and spectra (intensity versus energy).

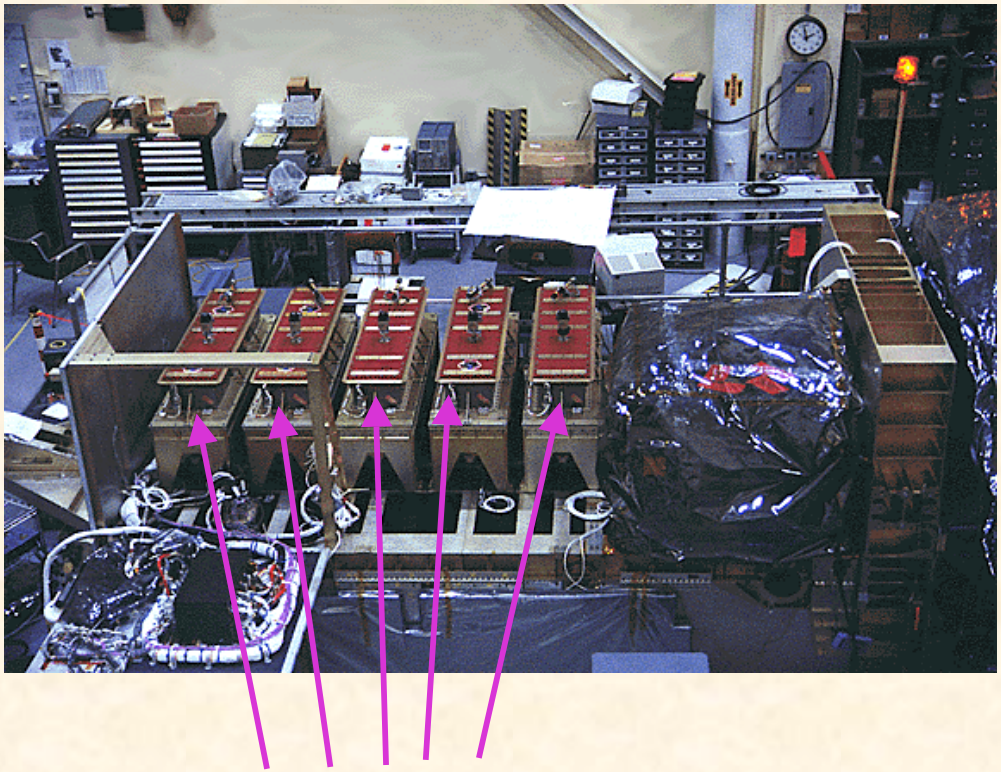
The RXTE satellite (an X-ray satellite with three instruments)



The PCA is a collection of five X-ray detectors that collect X-rays with energies from 2-60 keV (kilo-electronvolts).

The Proportional Counting Array (PCA)

The PCA consists of five identical Proportional Counting Units (PCUs). Each PCU counts X-ray photons from a specific region in the sky. They then record the energy of the X-rays. Each PCU made of a box containing Xenon gas, an electric field, and anode wires to collect charge.



the individual PCUs

Remember that RXTE is a satellite orbiting the Earth.
The detectors collect X-rays from celestial objects found in the direction they are pointed.

When an X-ray hits the PCA it strikes one of the five mylar-foil covered boxes (PCUs). The X-ray then passes through the foil to the gas inside.

Inside the foil-covered box is Xenon gas. The interaction of the X-ray photon with the Xenon gas is the basis of the X-ray detector.

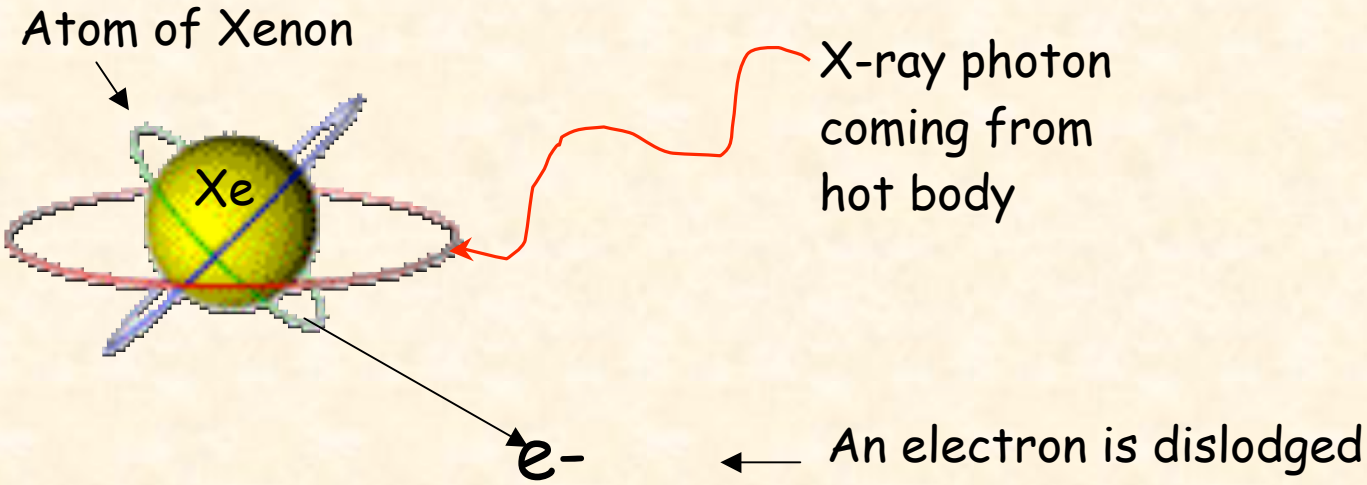
The Xenon Reaction

1. The X-ray photon enters a PCU and encounters a volume of Xenon gas.

2. The X-ray photon hits an atom of Xenon gas. The high energy of the photon causes an at least one electron from an inner shell to be released from the Xe atom.

3. At this point the initial energy of the X-ray photon has been changed into kinetic energy of the electron. The electron then gets pulled by the internal electric field, encountering other Xenon atoms as it speeds through the gas volume.

Visualization

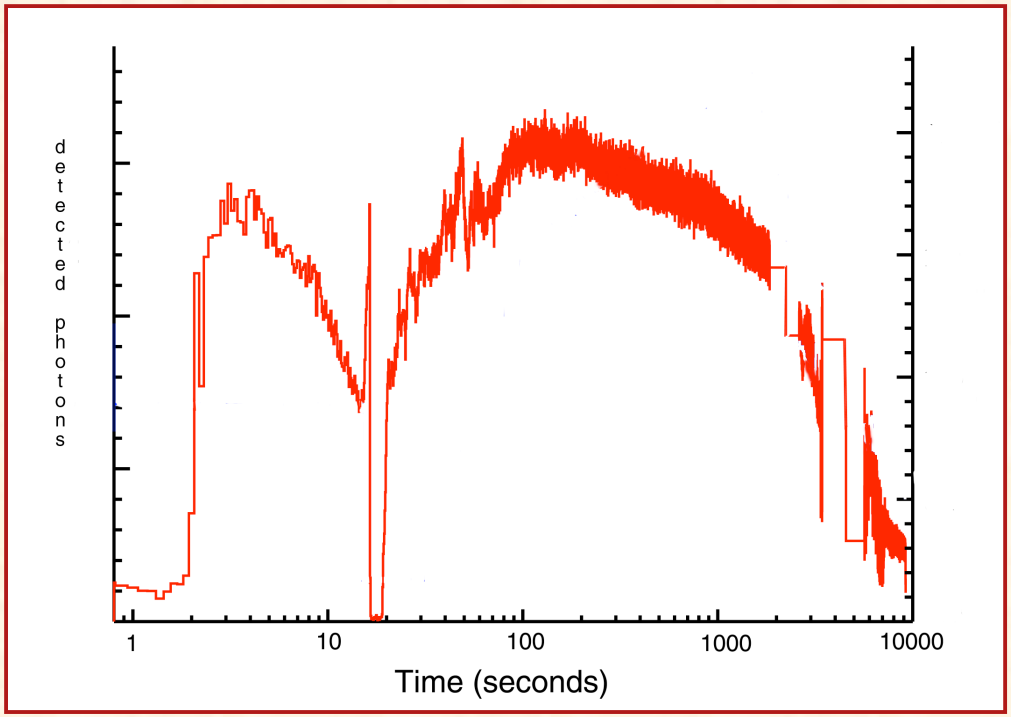


The electron that is released does not get "picked up" by other Xenon gas molecules that have lost electrons. Instead the electron is accelerated by the detector electric field, bumping out even more electrons in other Xenon atoms along its route to the anode wire of the PCU. This process happens over and over again for EACH photon that hits the Xe gas!!

What happens next?

1. The free electrons are pulled along by the electrical field of RXTE's PCU detector.
2. Inside the PCU detector there are anode wires. As the bunch of free electrons (from the original photon event) hit a wire, the PCU counts it as an electrical charge. The anode wire then measures the total charge from all the electrons in a single X-ray photon hit.
3. The counts (many per second) are read by the onboard computer. The total charge collected by the PCU detector is related to the energy of the original photon. The information is sent to Earth as a time series (how many counts per millisecond).

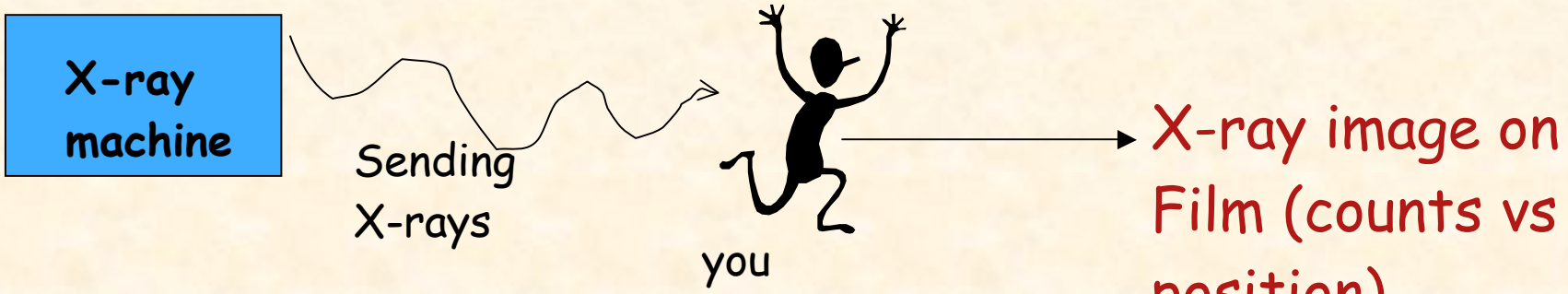
RXTE then sends the data to Earth via the TDRS satellite. This data is used by scientists to make light curves and spectra to analyze the results.



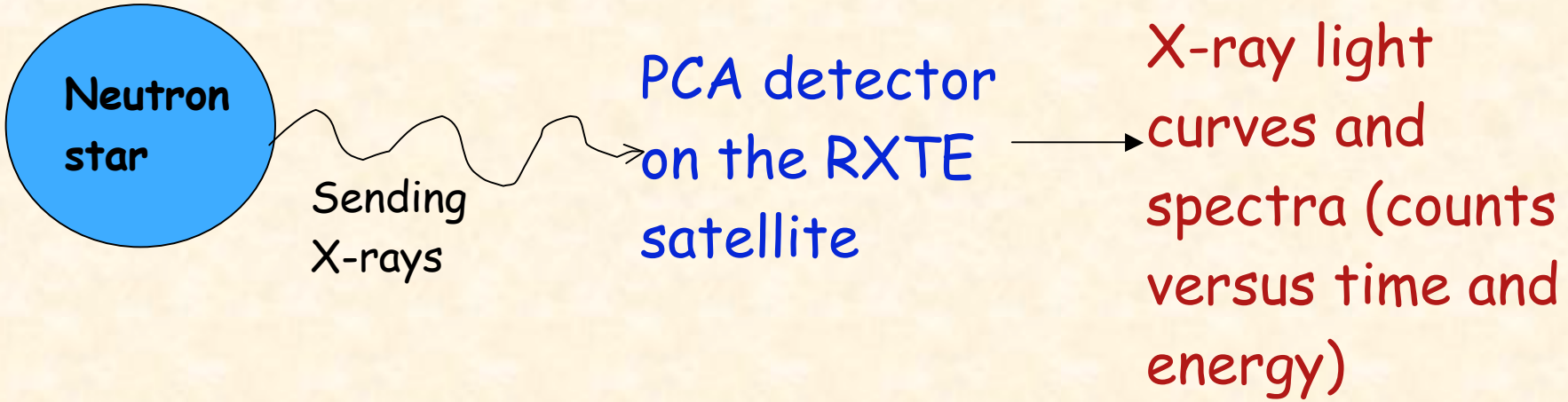
An example of a light curve from a bursting pulsar, measured by RXTE.

It is important to remember that the X-ray machine that your doctor uses and the X-ray detector that NASA use are very similar instruments.

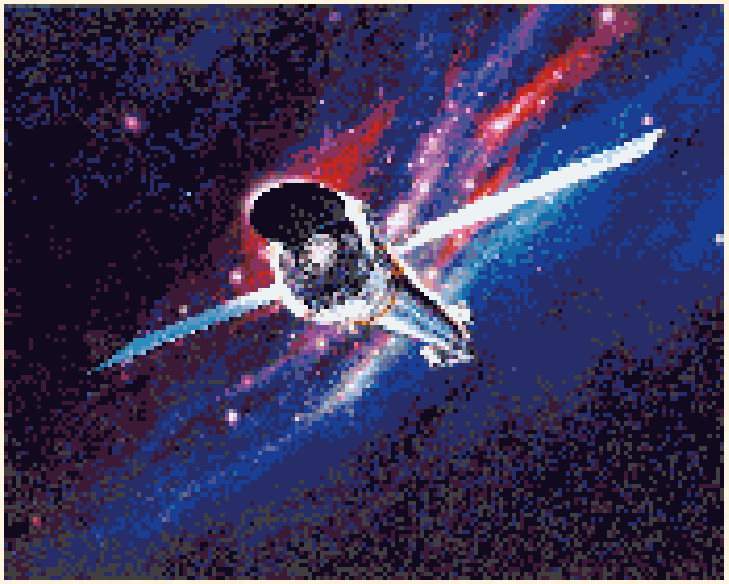
Your doctor uses the following recipe:



The astrophysicist uses the following recipe:



Chandra X-ray Observatory



The Chandra Observatory uses mirrors to focus the X-rays onto a tiny spot (about half the width of a human hair) on the focal plane. Other instruments then collect information about the X-rays from the focal plane.

The instruments are gathering data on the number, position, energy and time of arrival of the X-rays. This data then gets used to make images and complete observations of celestial objects.

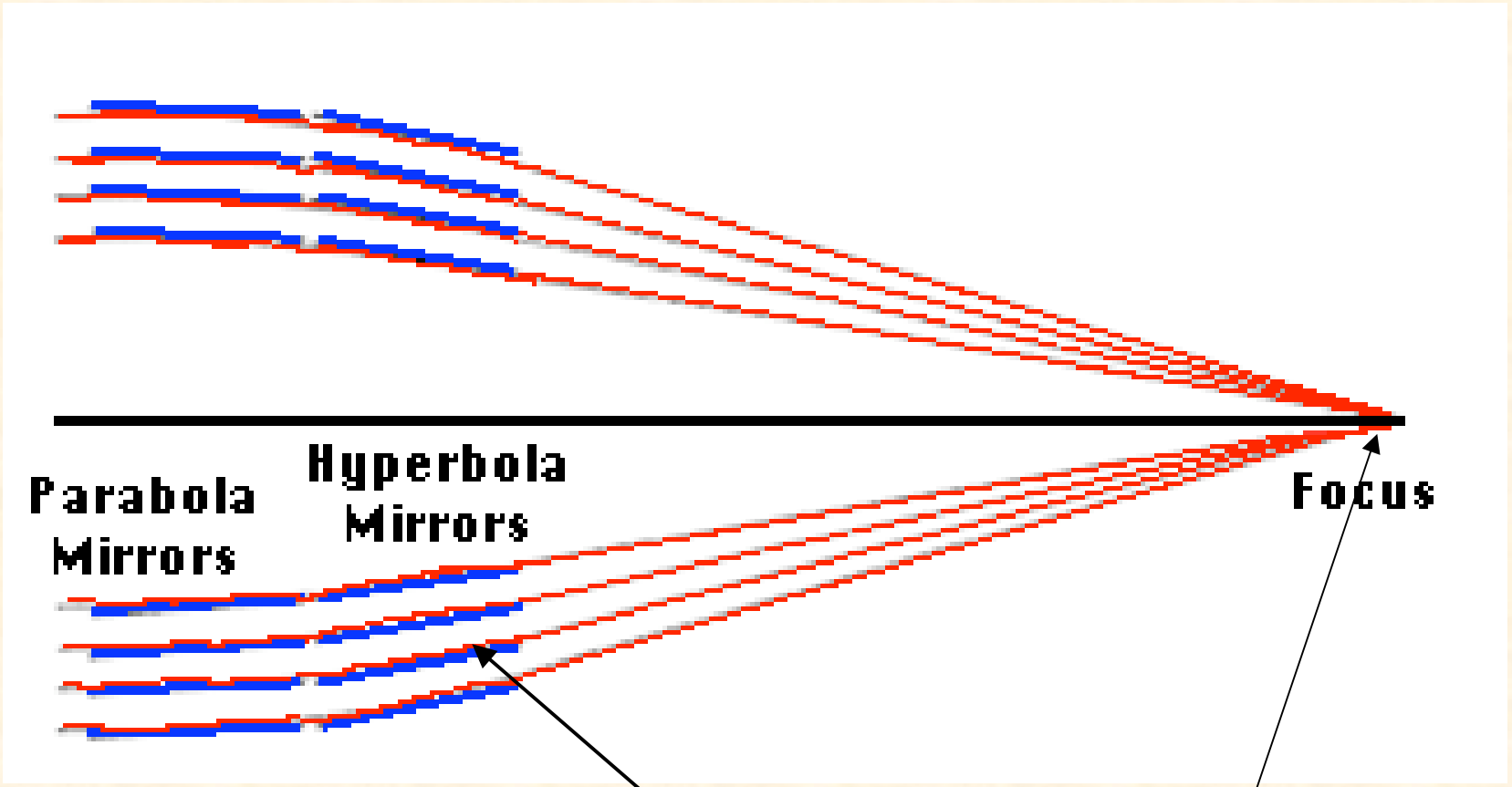
Since Chandra is an X-ray Telescope it's hardware is very different from the X-ray detectors.

Also, the telescope of Chandra is not the same as an optical telescope used on land to view the stars.

Chandra's X-ray Telescope

X-rays do not bounce off of mirrors like optical waves bounce off of an telescope mirror. Instead the X-rays would penetrate the mirror if aimed directly at it.

Because of this, the X-ray mirrors are set up so that the X-rays ricochet off of the surface of the mirrors. When they do this the X-rays look like rocks being skipped in a lake.

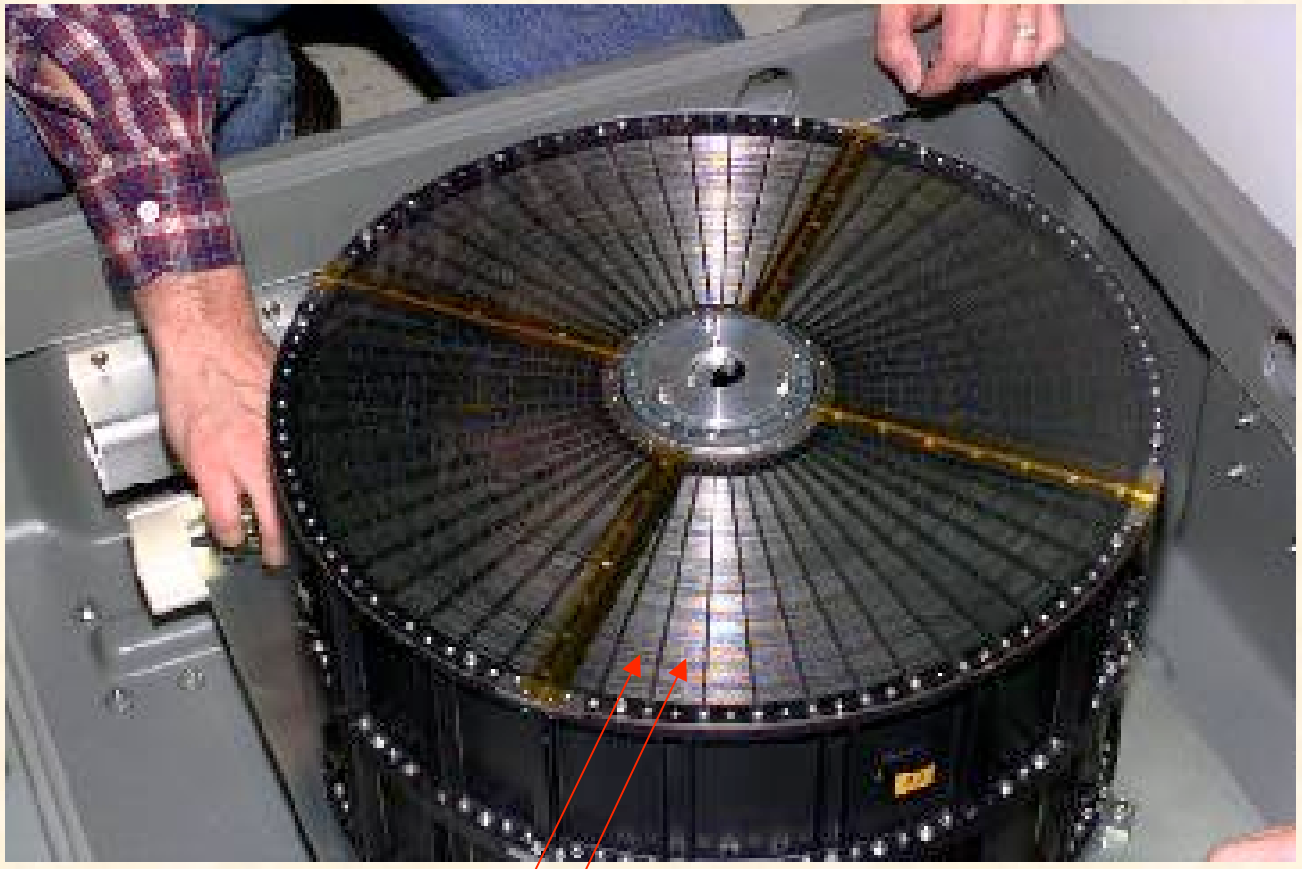


This picture shows the X-rays bouncing off of the mirrors and converging at one specific spot (the focus).

The Mirrors

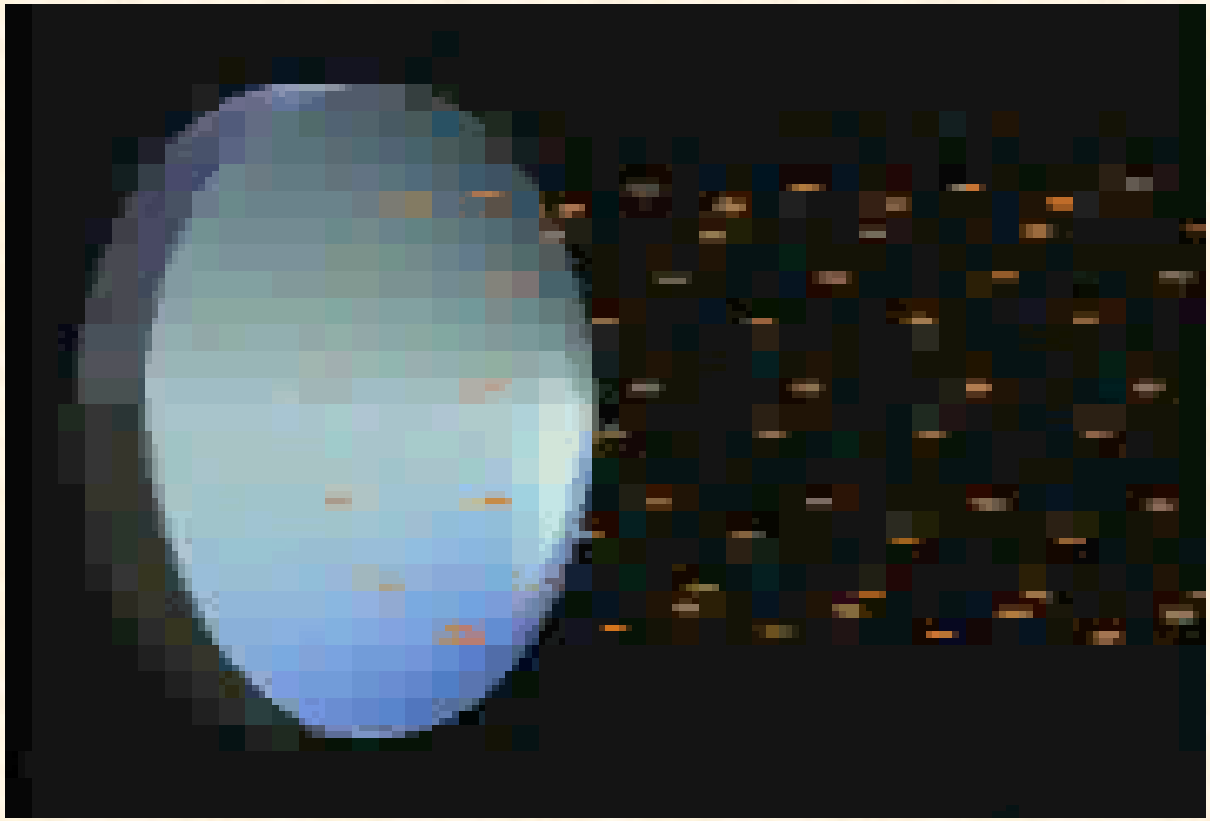
The mirrors look like barrels. Four mirror shells are nested inside one another. This helps to increase the total reflecting area of the telescope. All of the mirrors together focus the X-ray photons onto the detectors (similar to RXTE) which record the position and energy of the photons. The data is then analyzed and made into images of the celestial objects that produced the original X-ray emissions.

A picture of the Mirrors as they look assembled.



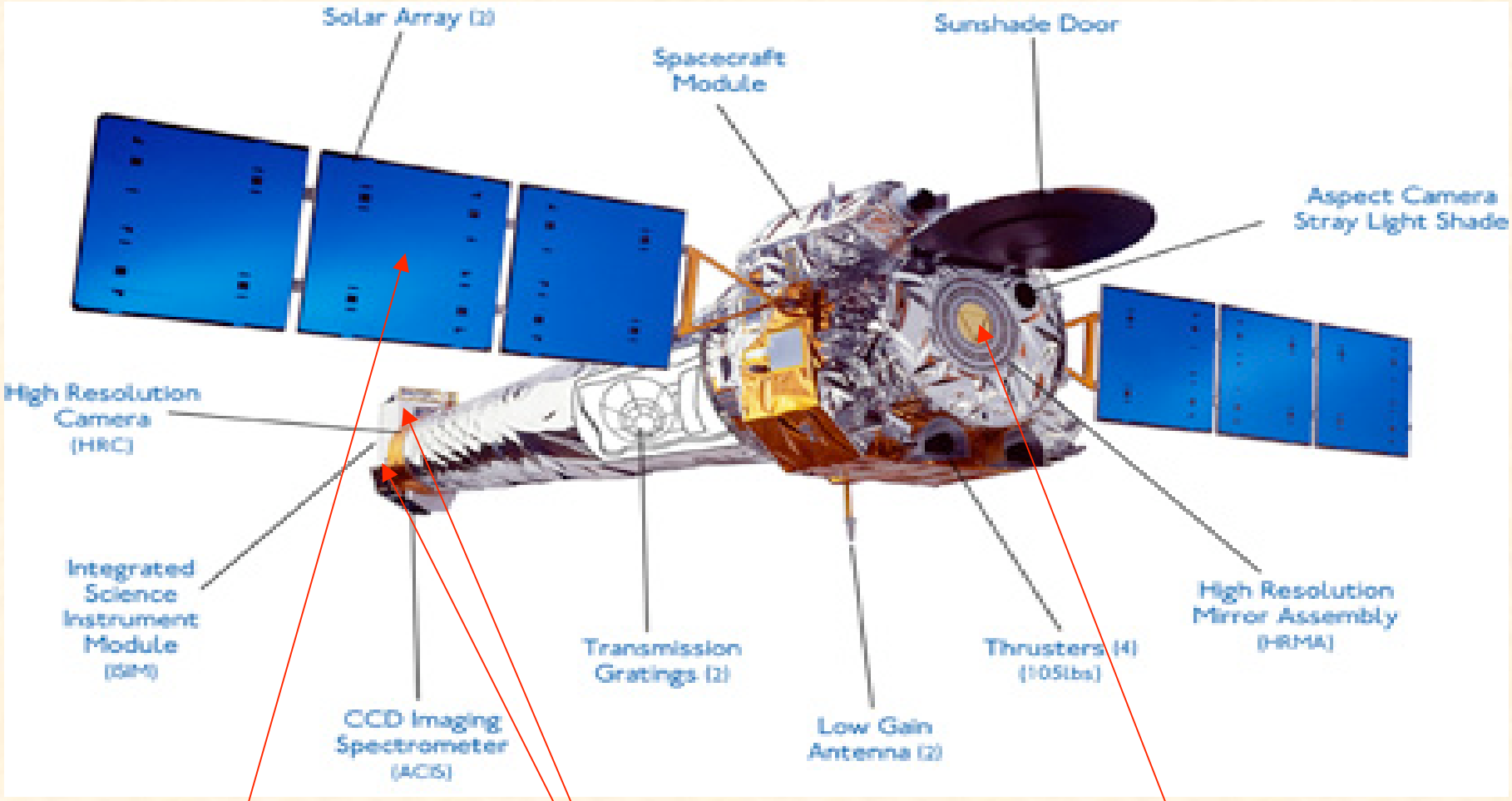
Notice the shape is round and it is made up of individual sections of mirrors. It is also smaller than many people expect.

Watch as the X-rays enter the telescope and are focused to the focal point by the mirrors.



From http://chandra.harvard.edu/resources/animations/mirror.mov

The Chandra X-ray Observatory

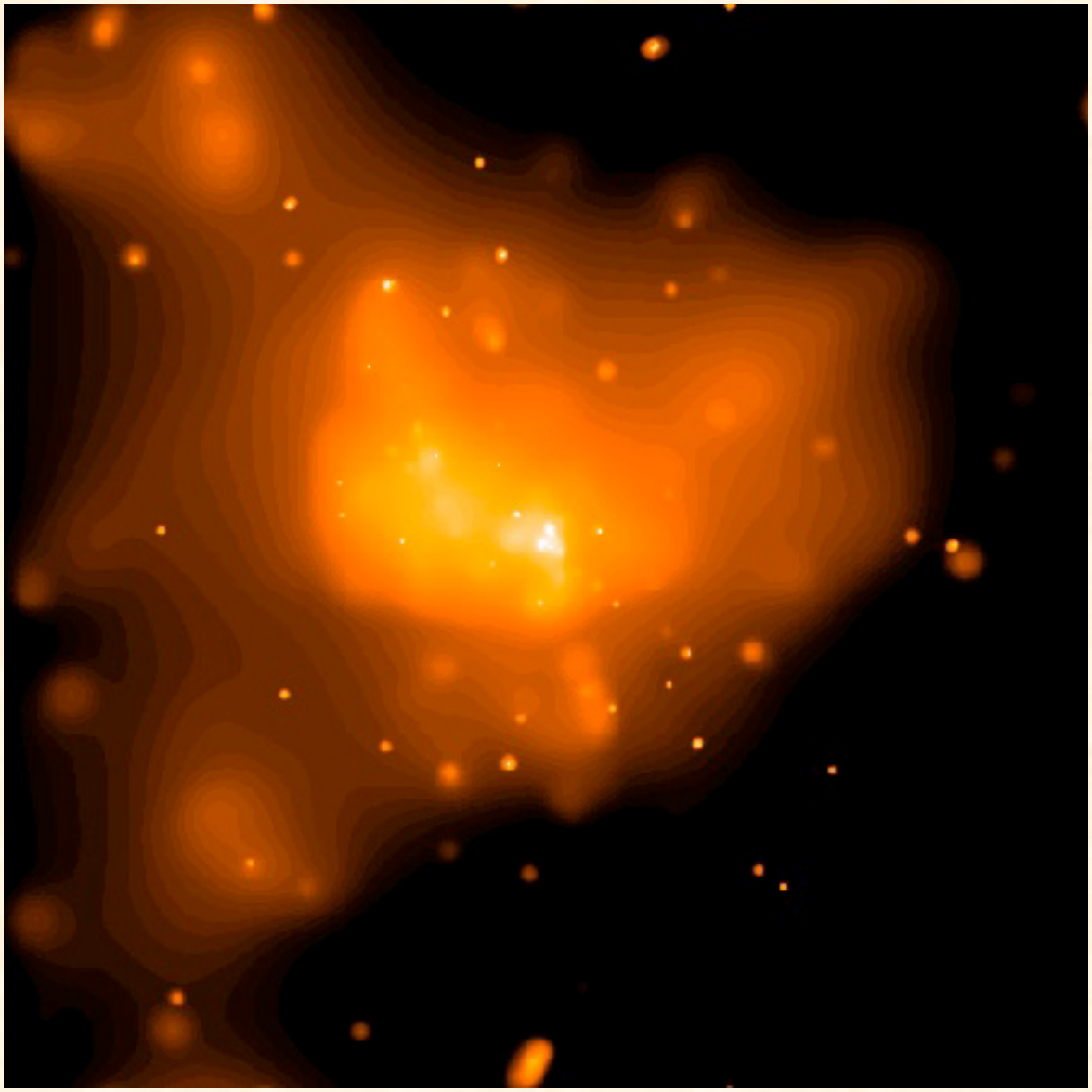


Source of electrical energy

Camera

X-ray Detector

Mirrors



A Chandra picture of the Sgr A supernova.

References

Picture of EM spectrum was taken from
http://astrosun.tn.cornell.edu/courses/astro201/emspectrum.htm

Picture of Radio telescope was taken from
http://www.oliverchamber.bc.ca/to_do/tours/observatory/observatory.htm

The picture and information of the first X-ray was taken from
http://imagers.gsfc.nasa.gov/ems/xrays.html

The picture and information of the galaxy Centaurus was taken from
http://chandra.harvard.edu/

The picture and information of the RXTE satellite was taken from
http://rxte.gsfc.nasa.gov/docs/xte/learning_center/ASM/getting_started.html

The RXTE picture was from http://heasarc.gsfc.nasa.gov/xte_weather/

The picture of the Earth's atmosphere was taken from
http://www.anl.gov/OPA/logos16-2/arm1.htm

The picture of the atom was taken from
http://casswww.ucsd.edu/archive/atoms_images1.html

The information for the X-ray machine came from
http://www.howstuffworks.com/question18.htm

The picture of Chandra was taken from
http://imagine.gsfc.nasa.gov/docs/sats_n_data/missions/chandra.html
Andhttp://chandra.harvard.edu/about/science_instruments.html

The picture of the chest X-ray was taken from
http://info.med.yale.edu/caim/stylemanual/Graphics/Manual/X-ray.GIF

The last Chandra picture was from http://chandra.harvard.edu/photo/cycle1/sgr_a/index.html