Part IV: How does the newest technology help us to understand the Universe?

All About the Microcalorimeter

Perhaps the most intriguing advance in X-ray astronomy instrumentation in the 1990s has been the development of the microcalorimeter, spearheaded by work at NASA's Goddard Space Flight Center. The microcalorimeter instrument designed at Goddard was called XRS, short for the X-ray Spectrometer.

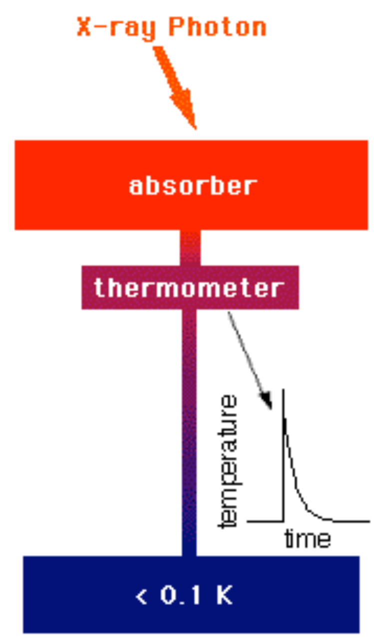
What is a Microcalorimeter?

A microcalorimeter is basically a thermal device made of an absorber, a thermistor, and a heat sink.

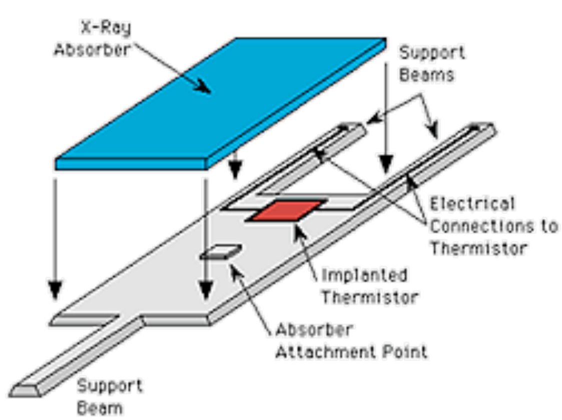
The absorber must do 3 things: absorb X-rays from space efficiently, quickly, completely convert the absorbed energy into heat (thermalize the energy), and have a low heat capacity. There is no material known, which excels at all 3 of these properties, so choosing the absorber material involves deciding on the best combination of them.

A thermistor is a device that changes its electrical resistance dramatically with a small change in temperature. Since a thermometer is any device that measures temperature, a thermistor is a kind of thermometer.

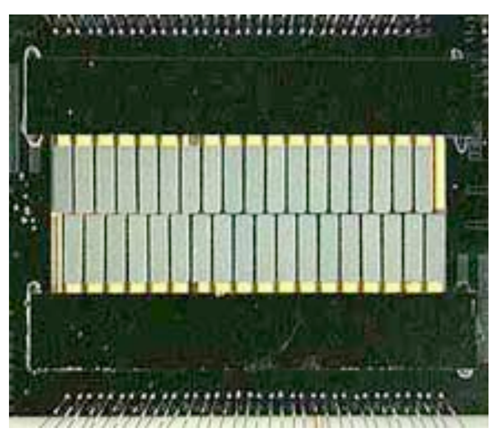
The combination of the absorber and the thermistor is what we call the "X-ray detector". The images in this section show a diagram of a detector, a photo of



The components of the calorimeter

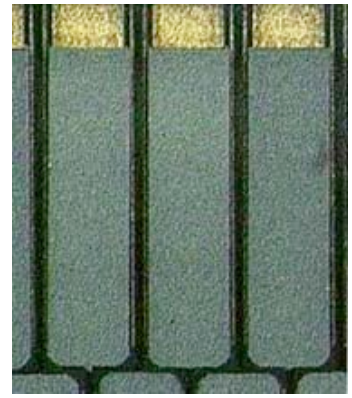


Schematic of the Calorimeter



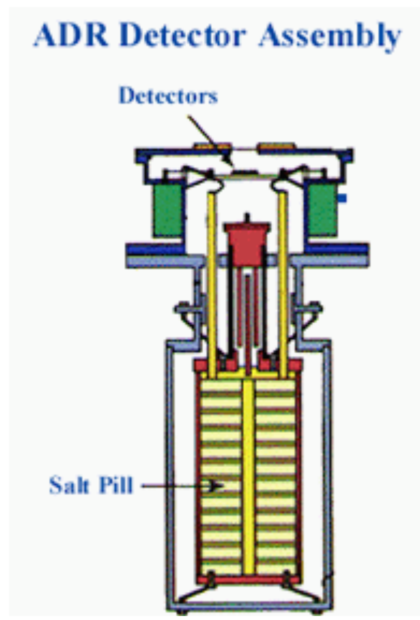
Array of Calorimeter Detectors

a detector array (they are the gray-green rectangles in the middle), and a close-up of the array. The array consists of 32 individual calorimeter detectors. You can (barely) see two black legs from each detector at the top of the image, and one leg from each detector squeezing between a pair of detectors at the bottom. These legs of the detector are what is called the "weak link" to the heat sink.



Close-up of Calorimeter

The heat sink is what absorbs heat from the detector, keeping it cool. In the case of a recently designed XRS, the heat sink used to keep the detector cool enough to work was a refrigeration unit called the Adiabatic Demagnetization Refrigerator (ADR). An ADR uses the magnetic properties of molecules in the "salt pill" to cool the detector to 60 milliKelvin (or 0.06 degrees above absolute zero).



How Does a Microcalorimeter Work?

An X-ray photon hits the absorber and knocks an electron loose from an atom of the absorber material. This photoelectron (so-called because a photon of light knocked it loose) rattles around in the absorber, ultimately raising the temperature of the absorber by a few milliKelvin (that is, a few thousandths of one degree Kelvin). The temperature-sensitive thermistor is partially isolated from the absorber, to give the absorber time to come into equilibrium before the thermistor begins to see the temperature rise. After a few milliseconds, the thermistor comes to the same temperature as the absorber, a few milliKelvin warmer than the heat sink, which is at 65 milliKelvin. We know it's a little strange to be talking about 'heat' when something is near absolute zero! Next, the thermistor begins to cool as the heat flows out the weak link (the "legs" of the detector) to the heat sink. After a few tens of milliseconds, the thermistor has returned to its normal operating temperature.

The temperature rise (ΔT, where Δ is the Greek letter pronounced “Delta”) measured by the thermistor is approximately proportional to the energy of the X-ray photon:

$$\Delta T \sim E/C$$

where ΔT is the change in temperature, E is the energy of the X-ray and C is the heat capacity of the absorber. So by measuring how much the temperature changes, we can determine the energy of the X-ray.

The Science

When an X-ray stops in a detector, it gives all of its energy to one electron. That electron can rattle around in the detector and give energy to other electrons. All these excited electrons would rather go back to their original energy. They want to return to what is called the ground state. Through scattering with other electrons or with vibrations in the solid itself, they can lose that extra energy. But that energy has to go somewhere. What it does is heat the solid and increase its temperature. If you measure the change in temperature, you can measure how much energy the X-ray originally had.
How are heat and energy and temperature all related? Heat is a manifestation of energy. Heat and energy are measured in the same units (Joules). If we are thinking of a large group of objects that can exchange energy with each other, we usually think of this energy as heat. An example would be the energy of a gas: we think of its energy as heat and measure it as a temperature. When an X-ray photon heats a solid, it gives its energy to the whole solid. On average, each atom is vibrating a little bit more than before the X-ray hit. Temperature is also the way we relate the total energy of a system to its state of disorder (entropy). A physical property called "heat capacity" tells us how much the temperature rises in a material if we put in a certain amount of energy.

Suppose we wanted to measure the temperature increase due to an X-ray photon being absorbed. We would want a very sensitive thermometer, something that had some physical property that changed a lot for a small change in temperature. We would also want the detector to have a small heat capacity, so its temperature would change a lot for a small change in energy. Finally, we would want to do the whole thing at very low temperatures, because at room temperature there would already be too much thermal energy in your detector to see the very small change in energy from the X-ray. That is what an X-ray calorimeter does. It uses a silicon thermistor, which has an electrical resistance, which changes dramatically with small changes in temperature. This thermistor has a low heat capacity, and operates at less than 0.1 K. That's Kelvin. Zero on the Kelvin scale is an absolute zero and represents the cessation of all thermal vibrations. Water freezes at 273 K. Nitrogen liquefies at 77 K. Helium liquefies at 4 K. and we operate calorimeters at less than 0.1 K! Calorimeters are able to get the best spectral resolution of any non-dispersive spectrometer.

Why Is the Microcalorimeter a Better Way to Detect X-ray Photons?

In proportional counters and CCDs, the energy of the X-ray photon is shared among many electrons. Each of these electrons ends up carrying a typical amount of energy, 3.65 eV in the case of the silicon-based CCDs. These electrons are then collected and counted by the electronics, and it's the number of the detected electrons that indicates the energy of the X-ray photon in a CCD detector system. An 3.65 keV X-ray photon, for example, will produce 1,000 electrons – give or take. There is an uncertainty in the number, because the details of the X-ray – matter interaction is different each time, giving a slightly different amount of energy to each electron. The uncertainty can be estimated by taking the square root of the number of electrons – 30 or so in this case, so the X-ray energy can be determined to an accuracy of 30/1000 ~ 3%. This is a fundamental limit of X-ray detectors that use conversion to electric charges. If you want a higher spectral resolution – and astrophysicists always do – you have to choose a detector that relies on a completely different principle, such as a microcalorimeter. As a result of its different approach, the microcalorimeter provides 10x better spectral resolution for detecting emission lines of iron.

For the Student

Using the text, and any external printed references, define the following terms: Kelvin, thermistor, and heat capacity.

Reference URLs:

Microcalorimeters

http://imagine.gsfc.nasa.gov/docs/science/how_l2/calorimeters.html
http://astrophysics.gsfc.nasa.gov/xrays/programs/astroe/eng/calorimeters.html

Thermodynamics

http://www.unidata.ucar.edu/staff/blynds/tmp.html

Activity: Identifying Light Energy by Temperature Changes

Days Needed 1
Grade level 9 - 12

Objectives

Students will determine the amount of heat energy (infrared light) released from a burning peanut. The students will relate this experiment to a microcalorimeter.

Science and Math Standards

NCTM

- Content Standard 2:
  - Mathematics as Communication
- Content Standard 4:
  - Mathematical Connections

NSES

- Content Standard A:
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry
- Content Standard B:
  - Structure of Atoms
  - Interactions of energy and matter
- Content Standard F:
  - Science and Technology

Prerequisites

- **Science Students** should understand that light is a form of energy, and the basics of the electromagnetic spectrum. Students should understand what a spectrum is.
- **Math Students** should be able to take measurements and use equations to calculate values.

Introduction

Students will explore hands-on how light energy can cause a change in temperature (in this case, in a flask of water). Students will relate what they find in this activity to how a microcalorimeter works to produce a spectrum of light from an incoming source. The microcalorimeter functions as energy dispersive x-ray detectors. This device picks up the energies of individual x-ray photons. The microcalorimeter is a sensitive thermometer that precisely measures the temperature variations due to the absorption of individual photons. Because it can measure very tiny temperature changes, this device will allow for the collection of spectra with extremely high-energy resolution, which will allow the measurement of chemical shifts due to different chemical bonding states, and the precise identification of incident photons.

Exploration

Materials

- paper clip
- peanut
- small aluminum pan
- flask
- ring stand and clamp,
- aluminum can with both ends open
- thermometer

Print out “Student Worksheet: Identifying Light Energy by Temperature Changes” for the class. Have them do the activity – the teacher should have a class discussion to go over the answers to the "Answer This" question.

Evaluation

Formative assessment and observation should be evident throughout the lesson. The worksheet, final questions during closure or a future quiz may serve as summative assessment.

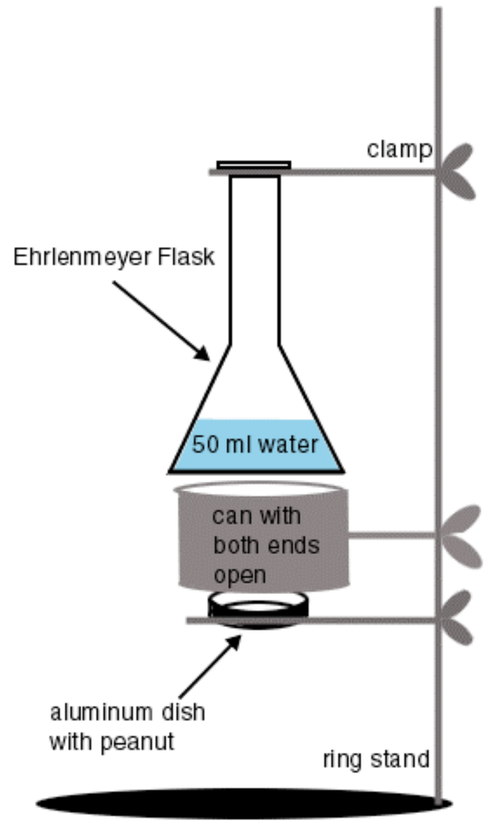
Closure

Ask students to take three minutes to write what they have found in this experiment, and to relate this knowledge to how a microcalorimeter works. What would limit the microcalorimeter's ability to produce a superior spectrum? What characteristics of a microcalorimeter make it an advance in spectrometer technology?

Student Worksheet
Identifying Light Energy by Temperature Changes

Procedure

1. As illustrated in the diagram set up your apparatus. Straighten out the paper clip and carefully thread the peanut onto the paper clip. You want to avoid as much as possible cracking the peanut.
2. Measure out 50 ml of water and pour the water into the flask. Determine the mass of 50 ml of water. Record the initial temperature of the water.
3. Place the small aluminum pan with peanut underneath the flask with the water in it. Using a match, light the peanut and allow it to burn. Make sure the apparatus is closely set up so that a large amount of heat is not lost into the air.
4. Record the final temperature of water after the peanut has stopped burning.
5. Answer the Think About questions on paper.



Think About

1. Describe what happened to the final temperature of water and explain why.
2. The energy emitted from the peanut is mostly infrared light (heat). Review the electromagnetic spectrum diagram. What would happen to the temperature of the water if the peanut were to emit the same number of photons but as ultraviolet light? Hint: Compare the energy of infrared and ultraviolet light.
3. Explain how you could use the temperature change of the water to create a spectrum of the light energy released by the burning peanut.
4. Relate this experiment to how a microcalorimeter works.

Activity: Identifying Elements in Supernova Remnants

Days Needed: 1 Class period
Grade level: 9 - 12

Objectives

Using X-ray line data, the students will identify elements contained in supernova remnants. Students will compare and contrast Supernova Remnant Spectral Data from different X-ray observatories.

Science and Math Standards

NCTM

- Content Standard 1:
  - Mathematics as Problem Solving
- Content Standard 4:
  - Mathematical Connections
- Content Standard 8
  - Geometry from an Algebraic Perspective

NSES

- Content Standard A:
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry
- Content Standard B:
  - Structure of Atoms
  - Interactions of energy and matter
- Content Standard G:
  - Nature of Scientific Knowledge

Prerequisites

- **Math Students** should have some pre-algebra, and be able to identify patterns and interpret graphs
- **Science Students** should have an understanding of spectra and how they are represented, an understanding of how atoms produce spectral lines. Students should understand how elements are produced and heated in supernova remnants.

Introduction

In groups of 2 or more, the students will be given several X-ray spectra from the ASCA X-ray satellite and will be asked to determine what elements are present using a chart listing elements and the energies of their emission lines. Following a class discussion of their results, they will then be given ASTRO-E spectra of the same sources and asked to determine which elements are present. (There will be much more accuracy with ASTRO-

E.) Finally, they will be given spectra from Constellation-X and asked to determine what elements are present. (There will be even better resolution with Constellation-X). Compare and contrast their findings as a class.

Exploration

Materials

- Simulated ASCA, Astro-E and Constellation-X spectra of Tycho supernova remnant
- Chart of X-ray lines corresponding to elements (print out student handout)

Simulated Supernova Remnant Spectra

- Simulated ASCA Spectrum
- Simulated Astro-E Spectrum
- Simulated Constellation-X Spectrum

Hand out the "Student Worksheet: Identifying Elements in Supernova Remnants" to the class.

Have the class do the activity and answer the questions on the worksheet. The teacher may collect and grade them.

Extension - Using Student Hera to Examine a Supernova Spectrum

Student Hera gives students the opportunity to analyze the same data sets that scientists use, using the same tools scientists use. The Student Hera web pages walk students through examining a spectrum a supernova remnant to identify elements present in the hot gas.

Student Hera Website: http://imagine.gsfc.nasa.gov/docs/teachers/hera/

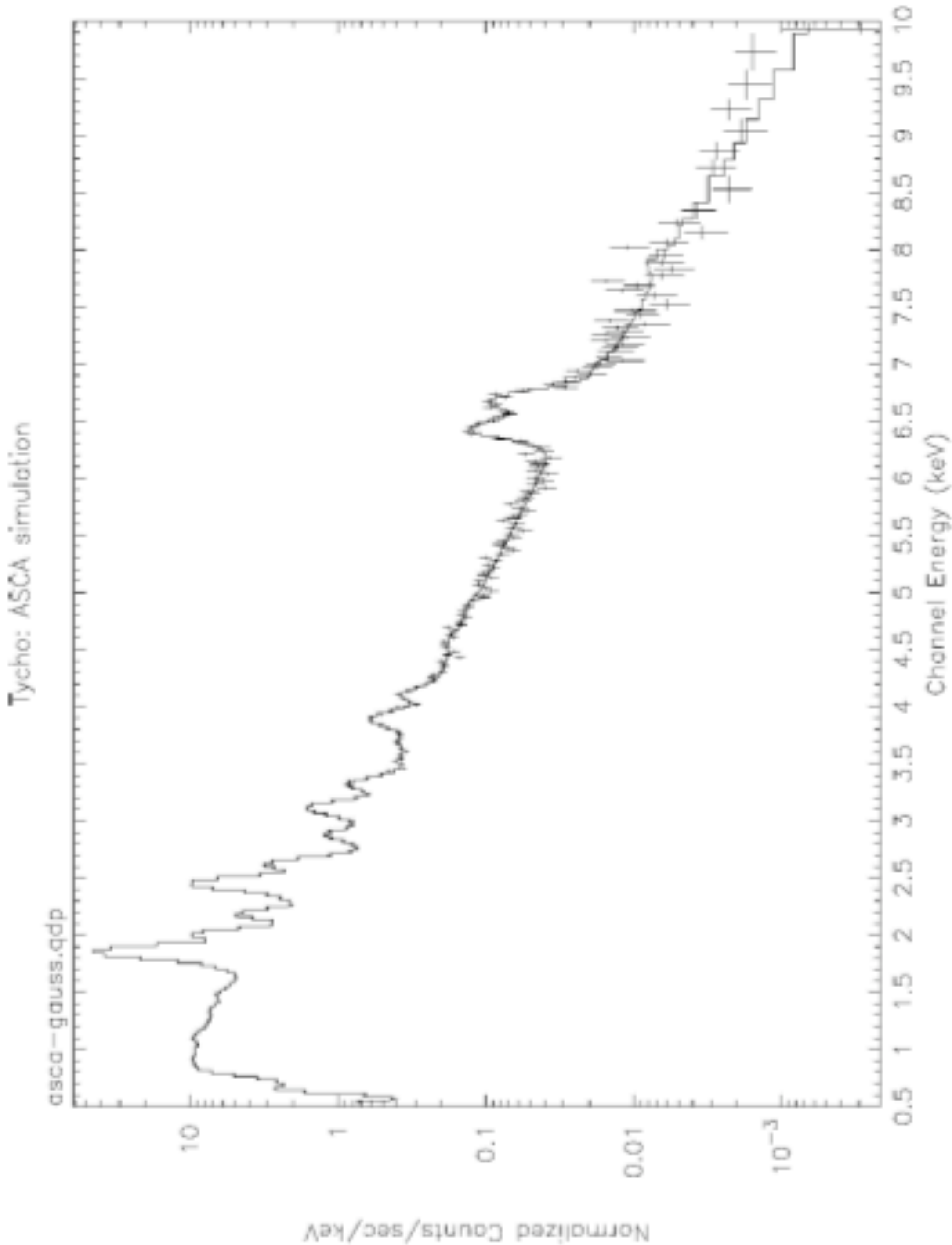
Evaluation

Formative assessment and observation should be evident throughout the lesson. The worksheet, final questions during closure or a future quiz may serve as summative assessment.

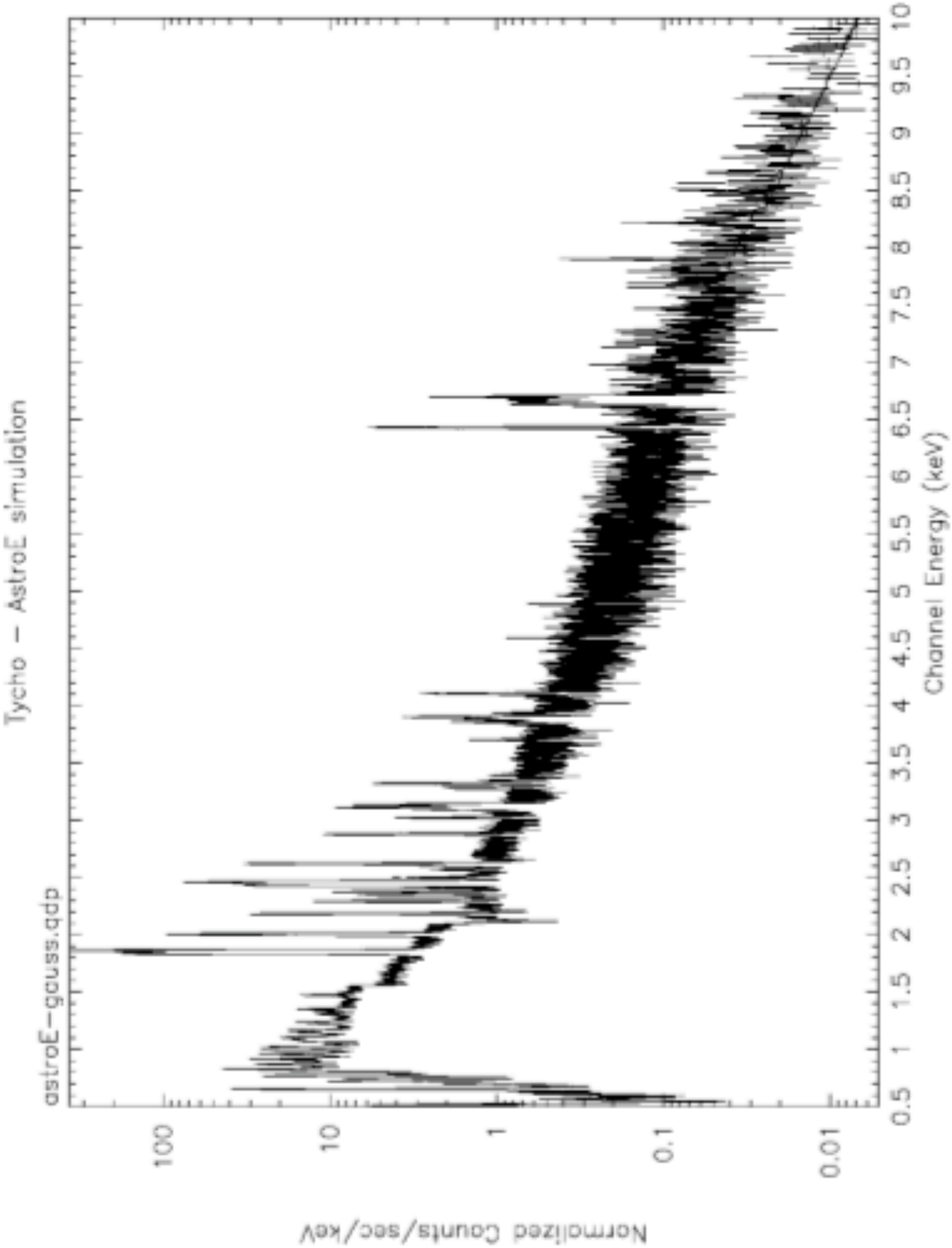
Closure

Direct students to write for ten minutes in their journals summarizing the lab and all procedures in this lesson. Encourage students to then share their findings and what they might have written in their journals.

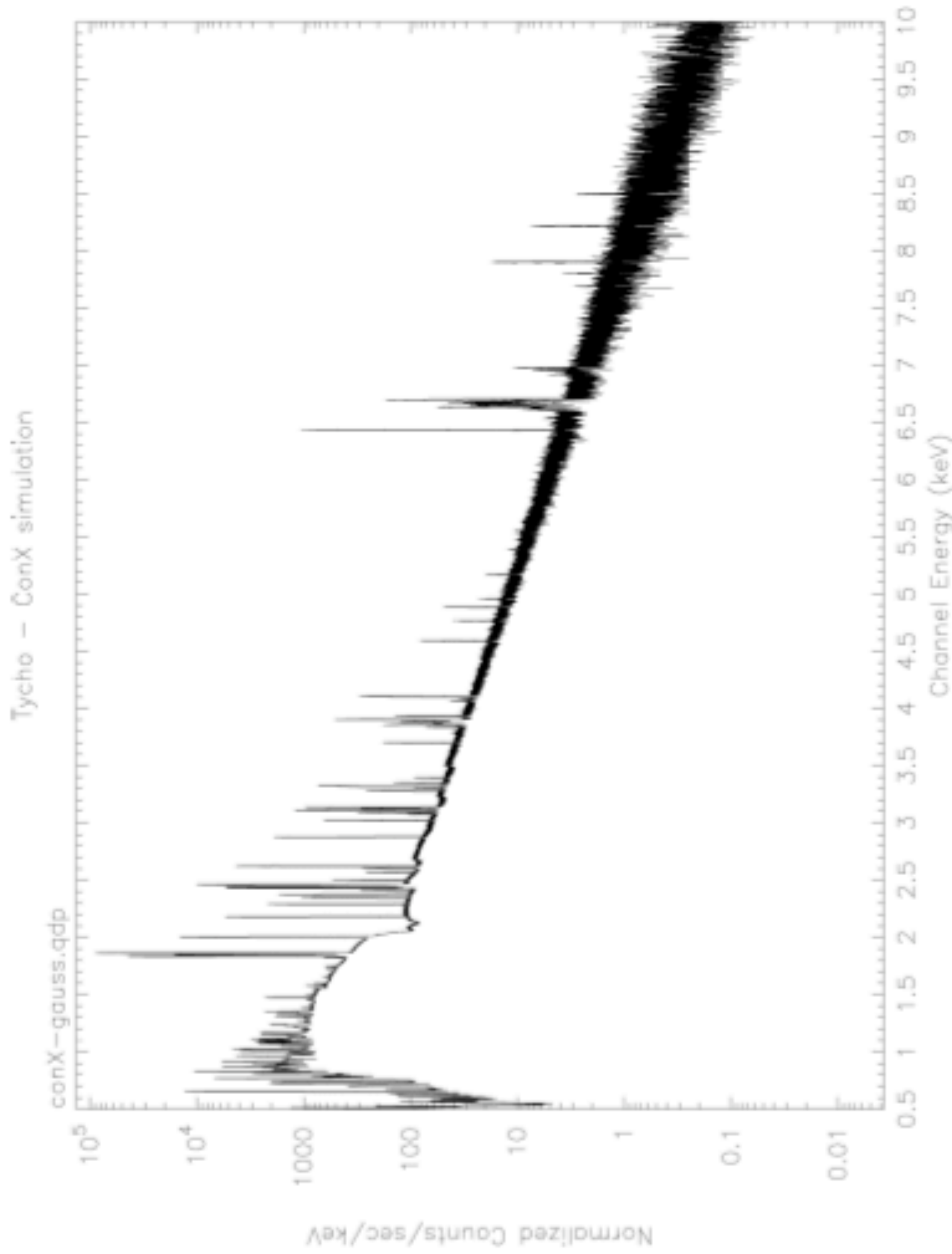
ASCA Simulated Spectrum



Astro-E Simulated Spectrum



Constellation-X Simulated Spectrum



Student Worksheet
Identifying Elements in Supernova Remnants

Procedure

1. Take out the three simulated spectra of the Tycho supernova remnant:
   - Simulated ASCA Spectrum
   - Simulated Astro-E Spectrum
   - Simulated Constellation-X Spectrum
2. Use the X-ray line chart below to identify the elements that correspond to the various peaks of emission seen in the spectra. (You can write directly on the printed spectra).
3. Answer the Think About questions.

Energies of Elemental Spectral Line Features

Element	Energy (keV)
O	0.547
O	0.654
Ne	0.922
Ne	1.022
Mg	1.352
Mg	1.471
Si	1.865
Si	2.006
S	2.461
S	2.632
Ar	3.140
Ar	3.323
Ca	3.903
Ca	4.108
Fe	6.701
Fe	6.973

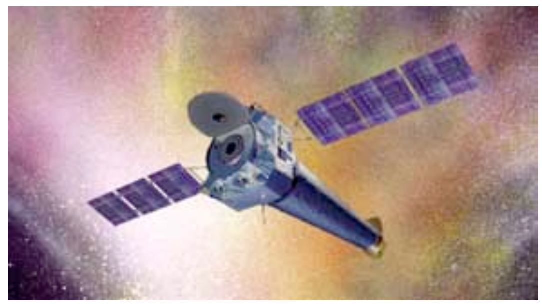
Think About

- Using spectra, how does an astronomer determine the composition of a star or supernova remnant?
- List some differences and similarities in the spectra from the three X-ray observatories (ASCA, Astro-E, and Constellation X).
- Were you able to determine with better accuracy what elements were present in the Astro-E spectra and Con-X spectra as compared to the ASCA spectra? If so, why?

A Plethora of X-ray Telescopes

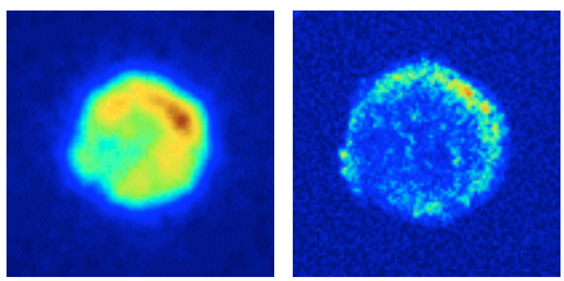
What observatories will we use in the coming years to explore the structure and evolution of the Universe? What observatories are we currently using? Chandra was launched from the space shuttle in 1999, ASTRO-E was attempted to be launched in Feb., 2000, and Constellation X-Ray Observatory is still being designed. Current X-ray observatories include RXTE and ASCA.

Chandra X-ray Observatory



NASA's Chandra X-ray Observatory, which was launched and deployed by Space Shuttle Columbia on July 23, 1999, is a very sophisticated X-ray observatory.

Chandra is designed to observe X-rays from high-energy regions of the universe, such as hot gas in the remnants of exploded stars. The two images of the Tycho supernova remnant shown below illustrate how higher resolution improves the quality of an image:



Low-resolution and high-resolution images of the Tycho supernova remnant

The image on the left is from a low-resolution detector on the Einstein Observatory. The image on the right, taken by the High Resolution Imager on the Einstein Observatory, has ten times better resolution, or finer detail (pixel area ten times smaller), than the one on the left. Chandra images will be fifty times better than the image on the right.

Chandra detects and images X-ray sources that are billions of light years away. The imaging mirrors on Chandra are some of the largest, most precisely shaped and aligned, and smoothest mirrors ever constructed. If the surface of Earth were as smooth as the Chandra mirrors, the highest mountain would be less than six feet tall! The images

Chandra makes are twenty-five times sharper than the best previous X-ray telescope. This focusing power is equivalent to the ability to read a newspaper at a distance of half a mile. Chandra's improved sensitivity is making possible more detailed studies of black holes, supernovae, and dark matter. Chandra will increase our understanding of the origin, evolution, and destiny of the Universe.

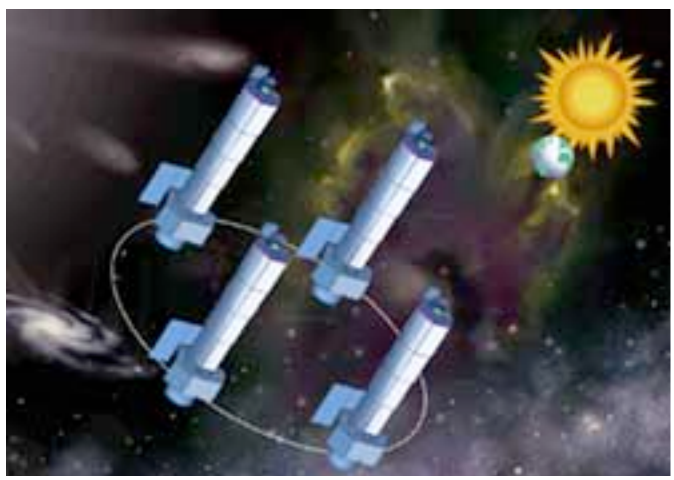
The Chandra telescope system consists of four pairs of mirrors and their support structure. The mirrors have to be exquisitely shaped and aligned nearly parallel to incoming X-rays. Thus they look more like nested glass barrels than the familiar dish shape of optical telescopes.

The function of the science instruments on Chandra is to record as accurately as possible the number, position and energy of the incoming X-rays. This information can be used to make an X-ray image and study other properties of the source, such as its temperature.

Chandra resides in an orbit approximately 6,214 by 86,992 miles in altitude.

For more information, see http://chandra.harvard.edu/pub.html.

Constellation-X



The Constellation-X Observatory will assist in putting together the missing pieces to understanding the X-ray Universe. The observatory consists of four X-ray telescopes or satellites that will detect a broader range of X-ray wavelengths than any current technology, especially X-rays at higher frequencies. Combining the observing power of four telescopes means that the total X-ray effective collecting area is much larger than that of previous telescopes. Constellation-X's total light collecting area is 3 square meters, a hundred times greater than the finest current instruments. The increased light gathering ability will allow Constellation-X to observe extremely faint X-ray emitting sources within our Galaxy and far beyond. Useful data from these faint sources will be collected in hours instead of days or weeks.

Constellation-X will be launched near the end of the coming decade. Its four satellites will orbit together in space about a few hundred miles from each other, and will detect and collect X-ray photons (instead of generating these photons like a medical X-ray machine). It will require several rocket missions to launch the entire observatory. The point at which the satellites will orbit is 1.5 million miles away from Earth where both the Sun's and Earth's gravitational pull are equal.

What will Constellation-X Observe?

Constellation-X will obtain spectra of distant sources, including supermassive black holes, X-ray binaries, galaxy clusters, supernova remnants, and stellar coronae. (See our Introduction to Spectroscopy for more information on spectra.) With a larger number of collected light photons, the resolution of spectroscopy increases tremendously. Higher resolution means that the collected data will be more quantitative. A high resolving power, for example, is necessary to distinguish the lithium satellite lines from the overlapping helium-like lines or transitions. Therefore, scientists will know exactly what elements are in X-ray sources such as supernova remnants, as well as their abundance, their density, and how fast they are moving. Spectra from Constellation-X are like "the fingerprint of elements in far-away stars and clouds of gas." High spectral resolution is essential to making unique identifications (from emission lines).

Constellation-X will be able to focus on smaller areas, which will automatically exclude picking up X-ray signals from the external medium of hot gas or other nearby sources. Its ability to discriminate among different X-ray wavelengths will be far better than any other X-ray telescope.

What questions will Constellation-X answer?

> "Constellation-X will be the next best thing to reaching out and touching supernova remnants, black holes, clusters of galaxies, and dark matter."

What happens close to a black hole?

The observatory will be able to measure the extreme gravitational force around a black hole. A black hole is defined by a surface called the event horizon, where gravity is so intense that nothing, not even light, can escape. Stellar matter is crushed into a single point behind the event horizon. Around black holes, interstellar gases move, heat up, and emit light energy in the form of X-rays. Constellation-X will be able to zoom to within a few miles of the event horizons of supermassive black holes in active galaxies outside our own Milky Way and obtain spectra of the gas found there. The spectra will be utilized to see the effects of how extreme gravity around a black hole affects the composition, pressure, density, temperature, and velocity of nearby gas. Scientists will eventually be able to collect quantitative data regarding the formation and evolution of these black holes residing in the centers of many (if not most) galaxies.

Recycling: The law of the Universe?

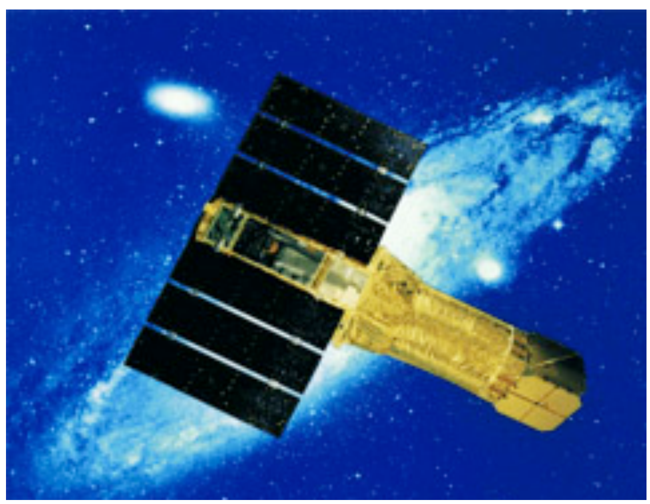
From individual stars to clusters of galaxies, the Universe is one big recycling machine. Constellation-X will produce detailed measurements of the formation of elements between carbon and zinc in stars, by observing supernova remnants. Galaxy Clusters are the largest objects in the Universe. They are complex, multi-component systems with hundreds of galaxies, hot gaseous intracluster medium, and dark matter, all evolving together. Constellation-X will study the chemical abundance of the intergalactic medium, and will also be able to measure the mass and motion of gas in the cores of galaxies. The motion of gases will be examined to determine if this gaseous motion is the cause of galactic mergers. Once it is understood how galaxies evolve and merge, a basis for understanding the structures of the Universe will perhaps develop.

Is there any matter missing from the Universe?

One of the biggest mysteries in modern astronomy is "What holds clusters of galaxies together?". While the earth holds the moon in place, what prevents galaxy clusters from spreading apart? The gravitational pull from the gases between the clusters is not strong enough. One major discovery made by scientists is the fact that most of the mass of galaxies, clusters, and the Universe is in the form of dark matter. Dark matter is in a form whereby it is not directly detectable. Scientists, however, know that dark matter exists by its strong gravitational effects. Even though dark matter cannot be directly observed, the Constellation Observatory will be able to map out its location. Perhaps the mystery of dark matter will begin to unfold.

ASCA

ASCA (formerly named Astro-D) is Japan's fourth cosmic X-ray astronomy mission, and the second for which the United States is providing part of the scientific payload. The satellite was successfully launched on February 20, 1993.



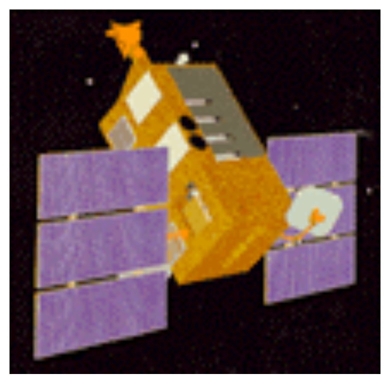
ASCA has played an important role in the astrophysicists' never-ending quest for better X-ray spectra. This has been achieved by a combination of lightweight telescopes with imaging detectors.

In designing ASCA's 4 X-Ray Telescopes (XRTs), Dr. Serlemitsos at GSFC and his team deliberately chose not to pursue the best (sharpest) X-ray images. Rather, they optimized the design for high collecting area (i.e., how much X-rays an XRT can collect from a given celestial source) within a tight weight constraint. They achieved this by using an innovative design of 'conical foil mirrors', which they had previously demonstrated on the Shuttle-based BBXRT mission in 1990. ASCA became the first satellite with XRTs that can operate up to 10 keV (previously, Einstein observatory's telescope was useful up to 4 keV). All 4 XRTs on ASCA point to the same region of the sky, further increasing the collecting power.

There are two types of detectors on board ASCA – two Gas Imaging Spectrometers (GIS) and two Solid-state Imaging Spectrometers (SIS), each behind its own XRT. Although the GIS's are excellent instruments, which have produced many important results, the SIS's are what astrophysicists were most excited about. At the heart of the SIS's are X-ray sensitive CCDs developed at MIT's Lincoln Laboratory. Each SIS consists of 4 CCD chips; each CCD consists of about 420 by 420 picture elements (or pixels). The energy of each X-ray photon striking a CCD is converted into electric charge, which is then measured by the on-board electronics. This gives X-ray CCDs a good spectral resolution that had not been available for routine use on faint X-ray sources. ASCA was the pioneer in the use of X-ray CCDs. More than 5 years later, the use of X-ray CCDs is becoming routine in newer X-ray astronomy satellites.

RXTE

The Rossi X-ray Timing Explorer (RXTE), named after astronomer Bruno Rossi, probes the physics of cosmic X-ray sources by making sensitive measurements of their variability over time scales ranging from milliseconds to years. How these sources behave over time is a source of important information about processes and structures in white-dwarf stars, X-ray binaries, neutron stars, pulsars, and black holes. With instruments sensitive to a wide range of X-ray energies (from 2-200 keV), RXTE is designed for studying known sources, detecting transient events, X-ray bursts, and periodic fluctuations in X-ray emissions.



The objectives of RXTE are to investigate:

- periodic, transient, and burst phenomena in the X-ray emission from a wide variety of objects,
- the characteristics of X-ray binaries, including the masses of the stars, their orbital properties, and the exchange of matter between them,
- the inner structure of neutron stars, and properties of their magnetic fields,
- the behavior of matter just before it falls into a black hole,
- effects of general relativity which can be seen only near a black hole,
- properties and effects of supermassive black holes in the centers of active galaxies,

- and the mechanisms which cause the emission of X-rays in all these objects.

RXTE has three instruments. The Proportional Counter Array (PCA) has five xenon gas proportional counter detectors (the X-rays interact with the electrons in the xenon gas) that are sensitive to X-rays with energies from 2-60 keV. The PCA has a large collecting area (6250 cm^2). The PCA's pointing area overlaps that of the HEXTE instrument, increasing the collecting area by another 1600 cm2. The High Energy X-ray Timing Experiment (HEXTE) extends the X-ray sensitivity of RXTE up to 200 keV, so that with the PCA, the two together form an excellent high resolution, sensitive X-ray detector. The All Sky Monitor (ASM) rotates in such a way as to scan most of the sky every 1.5 hours, at 2-10 keV, monitoring the long-term behavior of a number of the brightest X-ray sources, and giving observers an opportunity to spot any new phenomenon quickly.

ASTRO-E

ASTRO-E, launched in Feb, 2000, was to be the 5th in a series of Japanese astronomy satellites devoted to observations of celestial X-ray sources. Unfortunately, the first stage of the M-V launch vehicle had a burn through that caused loss of attitude control. By the time the second and third stages finished (successfully), there was not enough velocity to reach orbit. Losing ASTRO-E was a huge blow to the astronomical community. But sometimes this is the unfortunate consequence of launching a satellite on a rocket. ASTRO-E was not the first, and will not be the last satellite lost during its launch.

ASTRO-E was a joint Japanese-US mission, with the US contributing significantly to two of the three types of instruments on-board. It was developed at Japan's Institute of Space and Astronautical Science (ISAS) in collaboration with other Japanese institutions, as well as NASA's Goddard Space Flight Center and the Massachusetts Institute of Technology (MIT).

ASTRO-E was designed for "broad-band, high-sensitivity, high-resolution" spectroscopy. It consisted of 5 X-ray telescopes and a high-energy x-ray detector. Four of the telescopes focused x-rays onto imaging CCD detectors. The fifth telescope focused x-rays onto the microcalorimeter. Thus, Astro-E was not only sensitive to both low and high energy X-rays, but could distinguish very small differences in the energy of the X-ray photons that are being detected.

Some of the key themes that astronomers hoped that ASTRO-E would be able to advance are: When and where are the chemical elements created? What happens when matter falls onto a black hole? How do you heat gas to X-ray emitting temperatures?

Activity: Satellite Venn Diagram

Days Needed: 1
Grade Level: 11 - 12

Objectives

In this activity, students will use the background information they have read to organize a list of sources and objects, putting each item given in the appropriate part of the Venn diagram, depending on which instrument will study that item.

Science and Math Standards

NCTM

- Content Standard 1:
  - Mathematics as Problem Solving
- Content Standard 2:
  - Mathematics as Communication

NSES

- Content Standard A:
  - Unifying Concepts and Processes in Science
- Content Standard F:
  - Science and Technology

Prerequisites

- **Math Students** should understand Venn diagrams and the concepts of sets.
- **Science Students** should have an understanding of spectra, of astronomical observations, and have read the background material on Chandra, Astro-E and the microcalorimeter, and the Constellation X-ray Observatory.

Exploration

Print out "Student Worksheet: Satellite Venn Diagram" for the students.

Closure

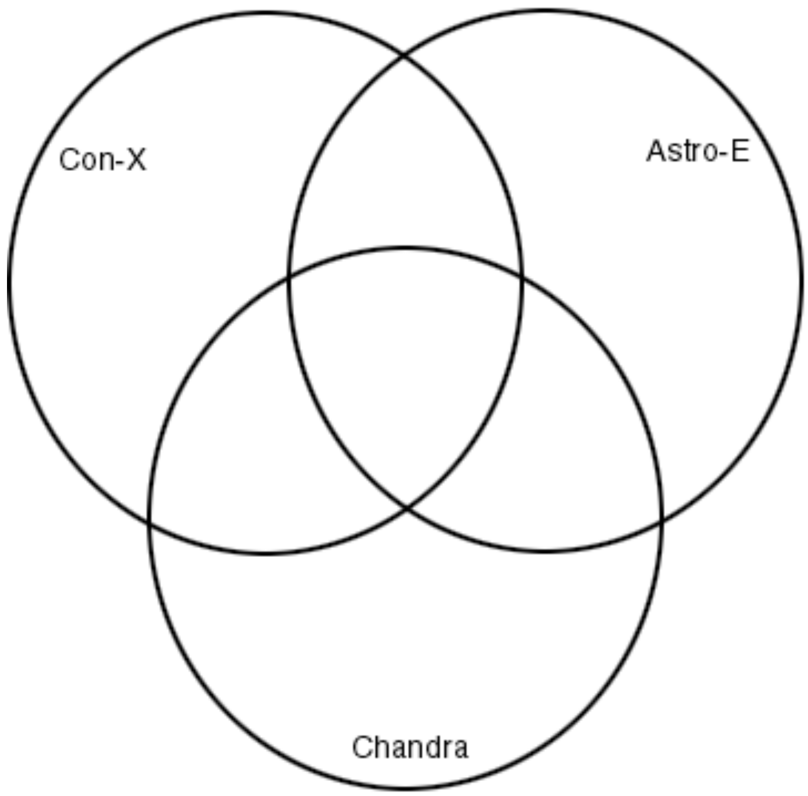
Students should write a five-minute summary of the capabilities of the three observatories, based on their Venn diagram. Do the observatories compliment each other? Where are they redundant?

Assessment

Students' understanding of the background material (on X-ray astronomy and on the three observatories) can be evaluated based on the accuracy of their Venn diagrams and the interpretation of the information on the Venn diagrams from their closure paper.

Student Handout
Satellite Venn Diagram

Listed below are characteristics of satellites, or descriptions of astronomical sources. After reading the background information on Chandra, Astro-E and the microcalorimeter, and Constellation-X, each listed characteristic should be placed in the appropriate place on a three-ring Venn diagram by their association with the satellites Chandra, Astro-E and/or Constellation-X. Properties of the microcalorimeter may be included as properties of Astro-E. An example of a three ring Venn diagram is shown below. Be sure to label appropriately the Venn diagram.



3-ring Venn Diagram

1. launched in 1999
2. will require several rocket missions to launch the entire observatory
3. consists of four individual satellites
4. perform detailed studies of black holes, supernovas, dark matter, origin, evolution, and destiny of the universe
5. launched in 2000
6. more quantitative data on abundance, velocity, temperature of gas

7. superior ability to discriminate amongst different x-rays wavelengths
8. flies more than 1/3 of the way to the moon
9. an array of 32 individual microcalorimeters
10. exquisitely shaped for pairs of mirrors
11. incorporates a three stage cooling system capable of operating the array at 60 mK for about two years
12. will be placed 1.5 million miles from Earth
13. images are 25-times sharper than previous x-ray telescopes
14. designed to study the universe in x-rays
15. detects broadest range of X-ray wavelengths
16. focusing power equivalent to the ability to read a newspaper a half a mile away
17. focus on smaller areas which will exclude picking up signals from external medium of hot gas
18. X-ray telescopes are one way to observe extremely hot matter with temperature of millions of degrees
19. data collected in hours instead days
20. observatory must be placed high above Earth's surface because Earth's atmosphere absorbs X-rays
21. deployment of observatory commanded by woman
22. 10-times higher spectral resolution for detecting emission from Iron
23. collecting areas 3 square meters which will detect x-ray sources 100-times fainter
24. a high resolution X-ray spectrometer based on a microcalorimeter array, four CCD X-ray cameras, and a hard X-ray telescope
25. detects and images X-ray sources billions of light years away

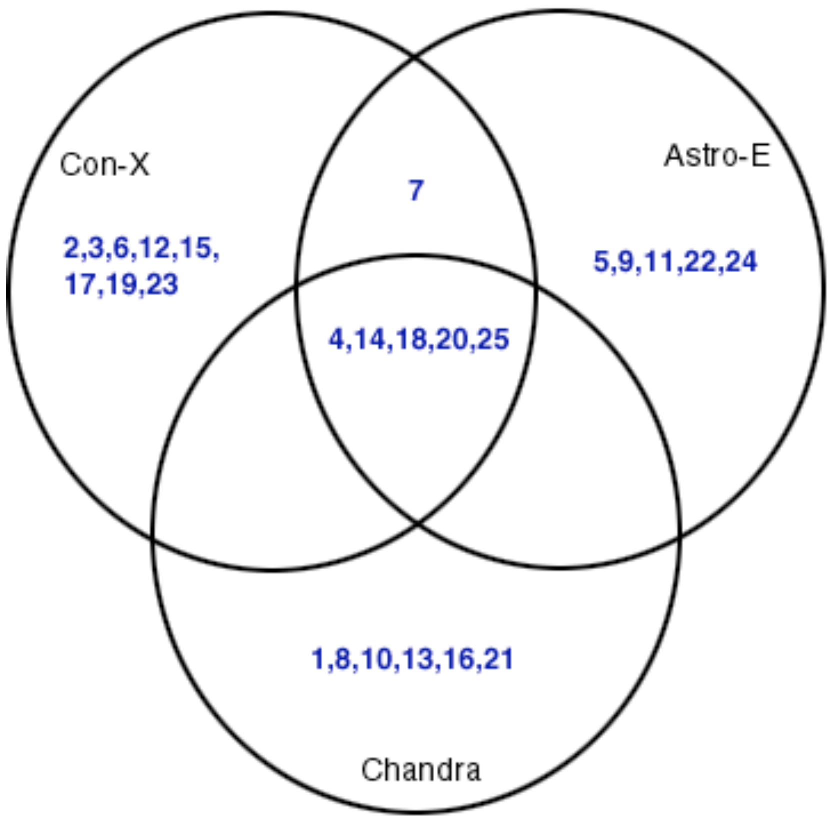
Thought Questions

In five minutes, write a summary of the capabilities of the three observatories, based on the Venn diagram. Do the observatories compliment each other? Where are they redundant?

KEY

Solution: Student Handout
Satellite Venn Diagram

The finished Venn diagram should look like this.



In the listing below, the correct answer is indicated in parentheses.

1. launched in 1999 (Chandra)
2. will require several rocket missions to launch the entire observatory (Con-X)
3. consists of four individual satellites (Con-X)
4. perform detailed studies of blackholes, supernovas, dark matter, origin, evolution, and destiny of the universe (Chandra, Astro-E, and Con-X)
5. launched in 2000 (Astro-E)
6. more quantitative data on abundance, velocity, temperature of gas (Con-X)
7. superior ability to discriminate amongst different x-rays wavelengths (Con-X and Astro-E)
8. flies more than 1/3 of the way to the moon (Chandra)
9. an array of 32 individual microcalorimeters (Astro-E)
10. exquisitely shaped for pairs of mirrors (Chandra)

11. incorporates a three stage cooling system capable of operating the array at 60 mK for about two years (Astro-E)
12. will be placed 1.5 million miles from Earth (Con-X)
13. images are 25x sharper than previous x-ray telescopes (Chandra)
14. designed to study the universe in x-rays (Chandra, Astro-E, and Con-X)
15. detects broadest range of x-ray wavelengths(Con-X)
16. focusing power equivalent to the ability to read a newspaper a half a mile away (Chandra)
17. focus on smaller areas which will exclude picking up signals from external medium of hot gas (Con-X)
18. X-ray telescopes are one way to observe extremely hot matter with temperature of millions of degrees (Chandra, Astro-E, and Con-X)
19. data collected in hours instead days (Con-X)
20. observatory must be placed high above Earth's surface because Earth's atmosphere absorbs X-rays (Chandra, Astro-E, and Con-X)
21. deployment of observatory commanded by woman (Chandra)
22. 10X higher spectral resolution for detecting emission from Iron (Astro-E)
23. collecting areas 3 square meters which will detect x-ray sources 100x fainter (Con-X)
24. a high resolution X-ray spectrometer based on a microcalorimeter array, four CCD X-ray cameras, and a hard X-ray telescope (Astro-E)
25. detects and images X-ray sources billions of light years away (Chandra, Astro-E, and Con-X)

Thought Questions

Each satellite represents an improvement over previous satellites. Chandra provides better imaging capabilities than previous satellites, and Astro-E provides better spectral resolution. In addition, Con-X improves spectral resolution beyond that of Astro-E.

The satellites are complementary because Chandra provides superior images, while Astro-E and Con-X provide superior spectra.

All the satellites must be placed above the Earth's atmosphere in order to study the universe in X-rays.

Activity: Writing to Persuade

Days Needed: 2
Grade Level: 11 - 12

Objectives

Students will demonstrate the ability to use text information and data to persuade a reading audience of the benefits of using microcalorimeter detectors to do X-ray astronomy. Students will summarize in their own words various reading selections, and will use results from previous exercises in their persuasion writing.

Science and Math Standards

NCTM

- Content Standard 2:
  - Mathematics as Communication

NSES

- Content Standard F:
  - Science and Technology
- Content Standard G:
  - Science in Personal and Social Perspectives

Prerequisites

- **Math Students** should have the ability to understand graphical data and statistics.
- **Science Students** should understand the concept of spectra, as well as the background material on the microcalorimeter. Students should have completed the activity to identify elements in supernova remnants.

Introduction

This final assignment will serve as closure. We've taken a close look at many different topics – yet they are all related. We've learned about doing astronomy at different energies, about the life cycles of the stars, about how new technology can improve our understanding of the way the Universe works. In this assignment, all that information will be integrated into a writing exercise.

Exploration

Give your students the following assignment:

The Assignment

Invent an X-ray satellite, name it, and draw a picture of it. This satellite will have a microcalorimeter on it. Write a one- to two-page persuasive letter addressed to your

Congressperson or essay for your local newspaper in order to obtain funding for your X-ray astronomy mission. Your writing should include the following:

- a one-paragraph description of what a microcalorimeter does
- the type of information and data that would be gathered by this satellite
- why its data would be unique to it and why other satellites like Chandra could not duplicate it.
- detailed arguments (at least three) as to why funding this project will benefit the scientific community as well as society.

Evaluation

The following scoring tool should be used to evaluate the persuasive essay. Listed are the items needed for a grade of excellence. Any one incorrect item or missing item will lower the grade one level.

- Concepts are appropriate and accurate
- Interpretation of data includes support
- Appropriate vocabulary, language mechanics, and complete sentences are used
- The writing is organized and focused
- Purpose of the writing is clearly carried out

Part IV: How does the newest technology help us to understand the Universe?

From: X-ray Spectroscopy and the Chemistry of Supernova Remnants

A Series of Lesson Plans by
Allie Hajian and Maggie Masetti (NASA/GSFC, Greenbelt, MD)
Rick Fowler (Crossland High School, Temple Hills, Maryland)
Angela Page (Hyattsville Elementary School, Hyattsville, Maryland)

Objectives

Students will read and write about the chemistry and spectroscopy of stars and supernova remnants, as well as understand their relevance and impact on human life. Students will also learn about cutting edge technology that will help us to build better instruments with which to study the Universe.

Each section has several pages of background material relevant to the associated activities and the lesson plan as a whole. The background sections include short exercises or thought questions developed to help the student reach a better understanding of the material presented. Each section also has activities developed by real teachers - designed to bring important concepts in astronomy right into the classroom. Each activity is correlated to national science and math standards for grades 9 - 12. These activities show how interrelated chemistry, physics, and astronomy really are.

Outline of Unit

Part I: How and Where are Elements Created?

- **Background:** *The Life Cycles of Stars: How Supernovae Are Formed* – Describes the life of a high-mass star - as well as its death in a giant supernova explosion.
- **Background**: *The Dispersion of Elements* – Describes how supernova explosions not only disperse the elements created inside a star, they create new elements.
- **Activity**: *Fusion Reactions* – In this activity, each student is given a card with an element produced inside stars on it - the students then form fusion reactions that occur within stars.

Part II: What is Electromagnetic (EM) Radiation? How is it created in atoms? What units are used to characterize EM radiation?

- **Background**: *How Do the Properties of Light Help Us to Study Supernovae and Their Remnants?* – Students learn about the electromagnetic spectrum.
- **Activity**: *Calculation Investigation* – Students learn about unit analysis by converting energies to wavelengths to frequencies.
- **Background**: *Atoms and Light Energy* – Describes how atoms emit light, and how we can use this to learn about astronomical objects.
- **Activity**: *Calculate the Energy!* – Students will calculate the energy differences in different energy states of the Bohr atom of Hydrogen.

Part III: What tools are used to identify elements? What importance do X-rays have to astronomy?

- **Background**: *Introduction to Spectroscopy* – Everything you ever wanted to know about spectroscopy but were afraid to ask!
- **Activity**: *Graphing Spectra* – Practice drawing graphs of spectra, and understanding the different ways spectra can be represented, as well as what each representation can tell us.
- **Activity**: *Flame Test* – A chemistry experiment that shows how heated elements emit different colors of light.
- **Activity**: *Design an Element Poster Advertisement* – Students will discuss what they have learned about atoms and elements in their own words, designing a poster advertisement for their chosen element. Students will use more than just their right brain to think about science!

Part IV: How does the newest technology help us to understand the Universe?

- **Background**: *All About The Microcalorimeter* – All about microcalorimeter technology, the next generation X-ray spectrometer.

- **Activity**: *Identifying Light Energy by Temperature Changes* – Learn first hand how a microcalorimeter really works
- **Activity**: *Identifying Elements in Supernova Remnants using Spectra* – Now the students get to take all they have learned and really apply it. Students will identify the elements present in a supernova remnant by analyzing its spectrum.
- **Background**: *A Plethora of X-ray Telescopes* – Learn about existing and future X-ray telescopes and what they hope to accomplish.
- **Activity**: *Satellite Venn Diagram* – Students will organize the information about X-ray observatories into a Venn diagram.
- **Activity**: *Writing Assignment* – As a closing activity, students will demonstrate the ability to use text information and data to persuade a reading audience of the benefits of using calorimeter detectors to do X-ray astronomy.