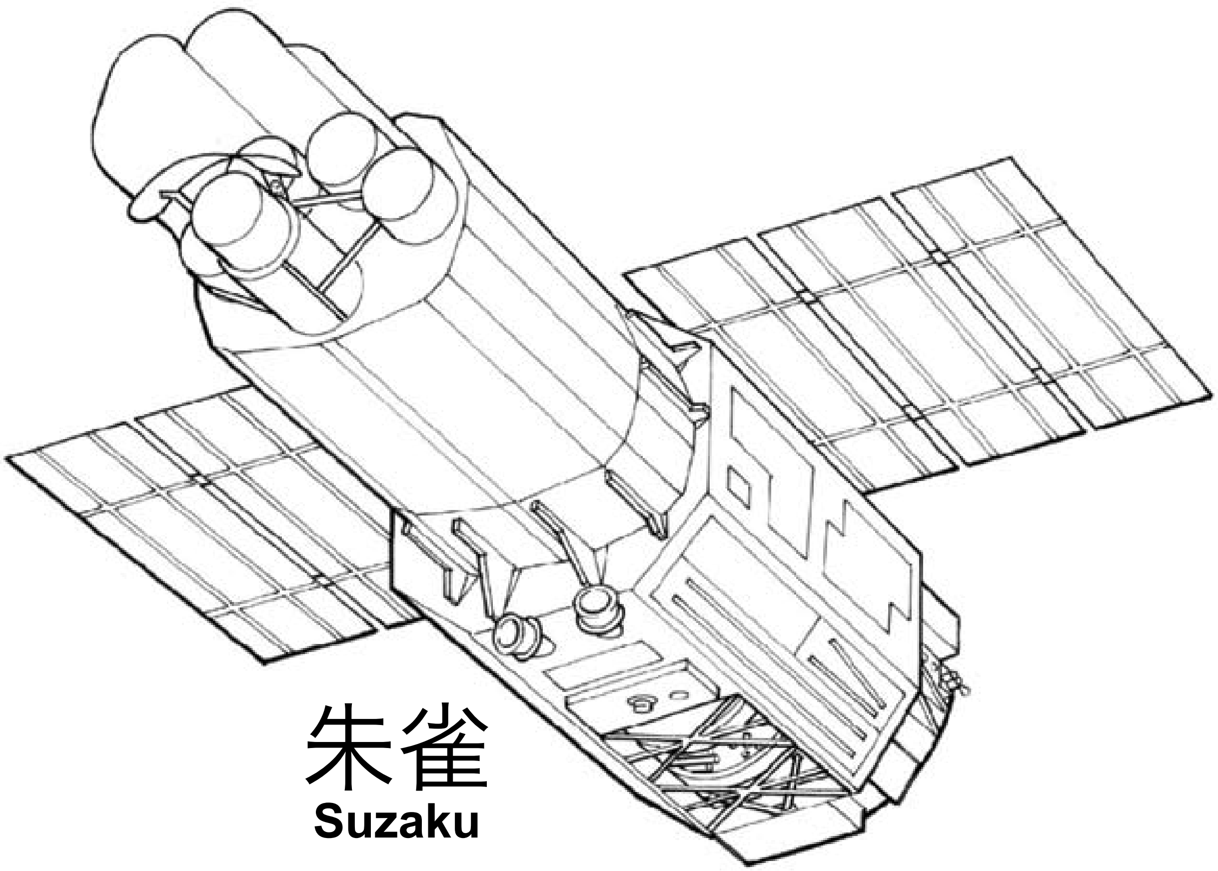
National Aeronautics and Space Administration

Building the Coolest X-ray Satellite



A Video Guide for Teachers

Grades 9-12

Probing the Structure & Evolution of the Cosmos
http://suzaku-epo.gsfc.nasa.gov/

The Suzaku Learning Center

Presents

“Building the Coolest X-ray Satellite”

Video Guide for Teachers

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This booklet is designed to be used with the “Building the Coolest X-ray Satellite” DVD, available from the Suzaku Learning Center.

http://suzaku-epo.gsfc.nasa.gov/

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I. Introduction

1. What is Astro-E2 (Suzaku)?

Astro-E2 is a Japanese satellite observatory which includes instruments built by NASA and Japan. The satellite is designed to observe the X-ray emission from objects such as black holes, supernova remnants and active galaxies. Two of the instruments were built at NASA's Goddard Space Flight Center: the X-ray Telescopes (XRT), and the X-ray Spectrometer (XRS). The telescopes utilize grazing optics to focus X-rays, and the spectrometer determines the energy of an X-ray by measuring the temperature rise in a wafer due to an incident X-ray. Astro-E2 is a re-build of the Astro-E mission, which suffered a launch failure in February 2000. Astro-E2 was successfully launched in July 2005, and was at that time renamed Suzaku. (In this guide we use both names.)

Additional information about Astro-E2/Suzaku can be found at http://suzaku-epo.gsfc.nasa.gov/.

2. "Building the Coolest X-ray Satellite: Astro-E2"

The video, "Building the Coolest X-ray Satellite: Astro-E2" tells the story of the development of the X-ray Telescopes and the X-ray Spectrometer. In addition, it includes profiles of scientists working on the mission, a description of the objects that Astro-E2 studies, and a look at how the instruments were put together. It shows how scientists and engineers overcome setbacks to deliver their instruments to Japan for final assembly and launch of the satellite. It also provides a window to how scientists from different cultures work together. The complete video is approximately 35 minutes long.

3. How to Use This Guide.

This guide provides classroom resources for viewing the video. In this guide, the video is divided into four chapters. The lesson for each chapter contains questions for students to focus on while viewing, and "Pause Points" to provide discussion of particular topics and scenes. There are also post-viewing questions for discussion. Each of these lessons takes about 45 minutes.

Student worksheets for each chapter are in Section XI of this guide. They can be used by the students as they watch the video, or used as a review immediately after students have finished watching the video.

Also included are extensive classroom activities for three of the video chapters, and a capstone activity in which students come to understand what we learn from spectroscopy.

The student worksheets, pause point questions, post-viewing questions, and the activities provide a wide variety of techniques for assessing student understanding of the topics.

This guide also gives additional information about some of the major components of the mission seen in the video. These include spectroscopy and how the XRS works, how the cooling system for the XRS works using an adiabatic demagnetization refrigerator (ADR), and a description of the different parts of the XRTs.

Using this guide will help make the viewing of the video an active learning experience.

4. Contents of the DVD

The DVD accompanying this guide presents the video in a number of ways:

- "Play Movie" will play the entire video.
- "Chapters" divides the movie into four chapters which follow this guide.
- "Teacher Resources" gives clips for each of the Pause Points in the guide.
- "Watch the Launch" is a four-minute video of the complete launch sequence.

For use in the classroom, you might show one chapter per class period, and engage in the "Focus for Viewing" questions. You can follow this by showing the "Pause Point" clips for that chapter, and discussing the related questions. After discussing the Pause Point questions, you may replay the Pause Point clips as needed.

5. Post-Launch Information

The video ends with the XRS leaving NASA/Goddard Space Flight Center, and a few scenes from the successful launch of Astro-E2 on July 10, 2005. After launch, Astro-E2 was renamed Suzaku. In this guide, we use both names.

After launch, the satellite deployed successfully, and the activation of the scientific instruments was begun. Initial calibration data from the XRS looked very promising and scientists were looking forward to a successful mission.

Unfortunately, a few weeks after launch, the XRS cooling system lost its liquid helium, and the XRS became inoperable. The mission continues with the two other instruments on-board, the X-ray Imaging Spectrometer, and the Hard X-ray Detector. The XRTs, which focus X-rays onto these instruments, are working as designed.

This loss was a deep disappointment to the scientists and engineers, but they continue to look for opportunities to build the instrument again and to fly it on another satellite. The principles of operation of the XRS remain useful teaching tools, and the video remains a useful lesson in how science is done.

You may wish to share this information with the students only after they have viewed the entire video. This may allow for further discussion on the risks of space-based astronomy.

6. Pre-requisites

The teacher should have some knowledge of basic astronomy and physics concepts. Concepts such as the electromagnetic spectrum, wavelength, temperature, heat, and basic principles of optics should be familiar. A basic understanding of astronomical objects such as black holes, supernovae, and galaxies is also recommended.

7. Standards Met by Video and Activities

Below is a summary of the National Science Education Standards and mathematics standards from the National Council of Teachers of Mathematics that are addressed in each of the chapters and activities. Each of these is for the grade 9-12 level. Some material in this guide is also appropriate for upper middle school.

Viewing Chapter 1: NSES Std G: Science as a human endeavor

Viewing Chapter 2: NSES Std G: Science as a human endeavor
Activity 1: NSES Std B: Interaction between matter and energy: waves, EM waves, discreet absorption/emission of light by atoms.

Viewing Chapter 3: NSES Std G: Science as a human endeavor
Activity 2: NSES Std B: Interactions between matter and energy: waves, EM waves, discreet nature of photons

Viewing Chapter 4: NSES Std G: Science as a human endeavor
Activity 3: NSES Std B: Conservation of energy: transfer of energy, nature of heat,
NSES Std E: Abilities of technological design: Choice of alternative design solutions
NCTM Stds: Algebra, Measurement, Problem Solving, Representation

Capstone Activity:
NSES Std A: Science as inquiry
NSES Std B: Interactions between matter and energy: waves, discreet absorption/emission of light by atoms
NSES Std G: Science as human endeavor: Contributions of individuals and teams, making public the results of research.
NCTM: Stds: Representation, Data Analysis, Problem Solving.

II. Video Chapter 1 – Astro-E2: History, People, and Science

Lesson Plan

Focus for Viewing

This video chapter gives background information about Astro-E, the mission that came before Astro-E2 (now known as Suzaku). It also introduces four individuals involved with Astro-E2 and gives some background on what motivated them to work for NASA. This chapter also discusses what the Astro-E2 mission will do.

Before viewing this chapter of the video, distribute to the students the "Worksheet for Chapter 1" (page 59) This worksheet gives the following Focus for Viewing questions:

- What was Astro-E?
- What happened to Astro-E?
- How did the scientists respond when they heard about the failure of Astro-E?
- What will Astro-E2 look for?
- How do black holes produce X-rays?

Viewing Guide

This chapter begins at the start of the video (0:00) and ends at 10:54. In the Chapters menu on the DVD, this chapter is called "Astro-E2: History, People, and Science." You may pause the video at the following Pause Points and guide the discussions given below. (Times noted are elapsed times from the beginning of the video.) In addition, each Pause Point has a separate clip that can be found in the Teacher Resources menu on the DVD. You may replay the clips as needed.

Pause Point 1 – Introduction to Astro-E2

Stop the video after the video title comes onto the screen -- "Building the Coolest X-Ray Satellite: Astro-E2." (3:50)

- Ask students to summarize what happened to the Astro-E mission, and how they think the team felt as they watched the rocket fail.
- Explain that the next section of the video gives background information about some of the members of the Astro-E2 mission team.
- Resume playing the video.

Pause Point 2 – Meet the Hosts

Stop the video after Dr. Weaver's introduction, as it fades to black. (7:12)

- Ask students to summarize what they learned about each team member. What knowledge and skills did each member bring to the Suzaku team? Suggested techniques might include a summary of 12 words or less, or pass around papers with each scientist's name, and have students add one item to the list.
- Ask students if any of the bios surprised them and challenged their perceptions of scientists.
- Explain that the next section of the video explains what Suzaku (Astro-E2) will do.
- Resume playing the video.

Pause Point 3 – What Will Astro-E2 Do?

Stop the video after Dr. Weaver introduces the concept of jets. (10:54)

- Ask students to summarize what they learned about black holes. What information surprised them?

Post-Viewing Activities

1. Discuss the Focus for Viewing questions in small groups. Have groups report their answers to the class.

2. Have partners or small groups discuss the following questions. Then discuss the answers with the whole class.
   - What do the actions of the NASA team after the failure of the rocket tell you about the people involved?
   - What do the telescopes do with regard to the X-rays from the black holes?
   - Why can’t we see the center of our galaxy in optical light?

3. Have students create additional questions about this chapter and ask them to the class.

4. Have students make a list of questions they are interested in that they think might be answered in the rest of the video.

III. Video Chapter 2 –
X-ray Spectroscopy and the Microcalorimeter

Lesson Plan

Focus for Viewing

This section of the video introduces viewers to the X-ray Spectrometer (XRS) being built at NASA Goddard Space Flight Center for Astro-E2. Drs. Boyce and Harrus explain what spectroscopy is and how spectroscopy helps us understand objects in space. Viewers are also introduced to members of the Japanese team.

Before viewing this chapter of the video, distribute to the students the "Worksheet for Chapter 2" (page 60) This worksheet gives the following Focus for Viewing questions:

- What does XRS stand for? What does it do?
- What is Chandra? How does Chandra relate to Suzaku (Astro-E2)?
- How do the US and Japanese teams look at their working relationship?
- What did you see in the footage from Japan that looks familiar? What looks different?
- In your own words, describe Dr. Harrus' stadium analogy. What do the balls represent? What do the games represent? What will Suzaku do?

Viewing Guide

This chapter begins at 10:54 and ends at 16:27. In the Chapters menu on the DVD, this chapter is called "X-ray Spectroscopy and the Microcalorimeter." You may pause the video at the following Pause Points and guide the discussions given below. (Times noted are elapsed times from the beginning of the video.) In addition, each Pause Point has a separate clip that can be found in the Teacher Resources menu on the DVD. You may replay the clips as needed.

Pause Point 4 – What is Spectroscopy? (Part I)

Stop the video during Dr. Harrus's stadium analogy, after she says, "So you want to get the balls, okay?" (12:27)

- Play the audio only (no picture) of Dr. Harrus's stadium analogy. Have students draw the analogy based on what they hear. (Alternately, mute the audio and allow students to provide their own narration.)
- Explain that during the next section of the video they will hear Dr. Harrus explain what the XRS instrument will do.
- Resume playing the video.

Pause Point 5 – What is Spectroscopy? (Part II)

Stop the video at the end of Dr. Harrus's foosball analogy, after she says, "Astro-E2 is going to tell you difference between those three." (13:43)

- In pairs, have students discuss the foosball analogy. Have them share their interpretations of what it means about the sensitivity of Suzaku's spectrometer.
- Tell students that in the next section of the video they will meet some of the Japanese scientists and learn about working in an international collaboration.

- Resume playing the video.

Pause Point 6 – A Multicultural Approach

Stop the video at the end of the cultural chapter, as the screen fades to black. (16:26)

- Ask students to describe the scenes from Japan.
- Ask students how they feel about the fact that the US team members speak very little Japanese, but the Japanese team members speak English.
- Ask students to describe their reactions to Dr. Fujimoto's comment about sweets. How does that comment relate to ideas or stereotypes that one culture has about another culture?
- In groups, have students consider the advantages and disadvantages of working internationally, especially with the time zone difference.

Post-Viewing Activities

1. Discuss the Focus for Viewing questions.

2. Have small groups develop a different analogy instead of the sports stadium to explain what Suzaku will do. Groups can make diagrams on poster board or use other methods to explain their ideas.

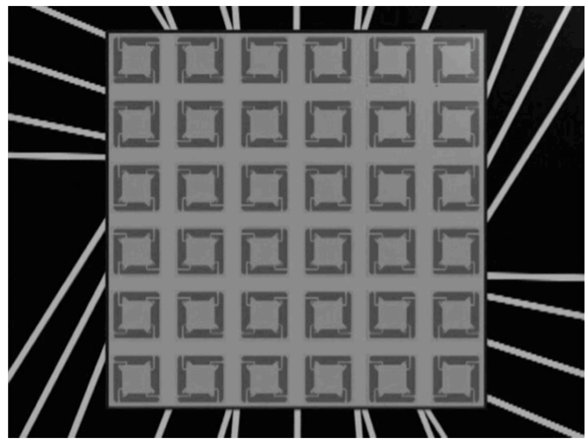
3. Have students create additional questions about this chapter and ask them to the class.

4. Have students make a list of questions they are interested in that they think might be answered in the rest of the video.

Background:
X-ray Spectroscopy and the XRS

In the video, Dr. Kilbourne presents the XRS as a microcalorimeter array. What is this array?

The XRS is essentially a collection of small thermometers called "calorimeters." Each calorimeter is 0.624 mm x 0.624 mm. Because of their small size, they are sometimes referred to as "microcalorimeters." They are put together to form a 6 x 6 array covering about 3.75 mm.



An illustration of the array of microcalorimeters. Lines leading away from the array represent electrical leads that carry the signal to the electronics.

The idea behind a calorimeter is that each photon carries some energy. If you deposit its energy in a really sensitive thermometer, you can measure the increase in temperature. By measuring their energy, you've performed spectroscopy!

It sounds simple but it is so difficult to do that until Astro-E2 nobody had succeeded in making a detector that worked in space. There are a few reasons why this is hard:

1. We are talking about a very small amount of energy (temperature). Even if these are very energetic photons by astronomical standards (the X-rays we are interested in are about 20,000 times more energetic than the photons from the Sun), each X-ray photon carries about 2×10^{-16} J, or about two billion times less than the energy of a hopping flea. This very small number is hard to measure.

2. A small variation on a big number is harder to see than the same variation on a small number. (A $1 mistake on a $1,000,000 transaction is harder to spot than a $1 mistake on a $5 deal.) The same applies to the measurement of the temperature with the calorimeter. This is one of the reasons why the detector must be kept at a very low temperature. We want to measure a very tiny difference in temperature between "before the photon arrives" and "after the photon arrives," so it's easier to spot if the initial temperature is also very small.

The other reason the instrument needs to be cold is linked to the way the instrument reacts to the heat. Each object reacts to heat according to a constant that characterizes its resistance to heat. For example, coal burns faster than iron because heat is transmitted in coal better than in iron. The constant that characterizes how much energy one should provide to an object to make its temperature rise by a degree is called "heat capacity". At a given energy, the difference of temperature measured increases when the heat capacity decreases – because one has to divide a constant number, the incoming energy, by a smaller number (the heat capacity).

Dr. Boyce says in the video that "the heat capacity of almost everything goes down very rapidly as you approach absolute zero." This means that at a low temperature, the difference in temperature measured for a given incoming photon is going to be larger than the one that would have been measured at room temperature. This is why the detector is operating at such a low temperature.

So how does it work?
The microcalorimeter is essentially like a thermometer measuring the increase in temperature imparted to one pixel (one of the 31 calorimeters in use on the array). When a photon arrives on the array, it deposits all of its energy on one pixel. This energy increases the temperature of the pixel and this increase is measured and sent out along with the number of the pixel hit by the photon and the time it happens. Then the energy dissipates and the array is ready for another photon to come in.

Why would anyone want to measure the energy of photons that arrive from space?
The energy of the photon provides information on how they were produced, which leads to a better understanding of what is happening in the energetic distant objects that produced these photons. This gives us clues about the story of the Universe.

One can look at this with the analogy of the different games, given by Dr. Harrus in the video. Once you determine what kind of ball it is (the energy of the photon), you may have a better idea of what kind of game is being played (what produced it). The XRS is a very good detector so it can tell the tiny difference between balls that looks almost identical (ping-pong and foosballs).

Activity 1:
Modeling and Using the Electromagnetic Spectrum
X-rays carry energy, which may change the temperature of an absorber and provide data about the place and/or object it came from.

Time required: Approximately 30 min. Minimal prep time to collect objects used.
Objective:
- Visualize the concept of photons
- Relate different wavelengths of light to energy associated with photons of that light.
- Associate X-rays with high-energy photons.

Standards: See section 7 of the Introduction (p. 4)

Student Audience:
This activity is appropriate for both middle and high school classes in Physical Science, Introductory and/or Conceptual Physics, and General Physics.

Overview:
Knowing the regions and characteristics of the electromagnetic spectrum is like learning the ABCs of the universe. This activity engages students in an exploration that leads them to the conclusion that regions vary according to energy per photon, and connects with Dr. Ilana Harrus' explanation of observing a sporting event from outside the stadium. Pause Points 4 and 5 ("What is Spectroscopy?") serve as an introduction to this activity.

Materials:
Ping pong ball, beach ball, basketball, tennis ball, football, baseball, golf ball, bowling ball. (Feel free to substitute with materials that are convenient. Provide balls with a variety of weights.)

Sequence of events:
1. Students should read: http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html (you may want to limit the reading to the first half of the page) and/or view a 21 sec audio/video clip accessible at http://imagine.gsfc.nasa.gov/docs/science/know_l2/emspectrum.html.

2. Thought experiment and demonstration: Ask students to imagine the objects in the front of the room being tossed against a pane of glass, like that in a window. First the ping pong ball. Questions to discuss:
- Would the ping-pong ball be stopped by the glass or go through it?
- Would it change or damage the glass at all?
- Next, what about the beach ball? Tennis ball? Etc.

As a class or in groups, complete the following chart associated with event 2 above:

Object	Effect on glass if tossed	Effect on glass if thrown very hard
Golf Ball		
Beach Ball		
Football		
Basketball		
Ping Pong Ball		
Baseball		
Tennis Ball		
What is different about each ball and how it is thrown that causes everything from no damage to certain damage?		

(Suggestion: Take a few minutes to debrief and guide student groups to conclude that the faster balls cause more damage and have more energy (kinetic). You may wish to discuss the role that mass plays, but this may also lead to quite a divergent discussion.)

3. Relating these models to the EM spectrum.
Prompt: Different wavelengths of light have different energies. From least to greatest energies they are:

- Radio
- Microwave
- Infrared
- Visible
- Ultraviolet
- X-ray
- Gamma

We want to model each of the above wavelengths with the objects listed above. Which of the above would be best associated with the objects in Part 2 above?

Wavelength	Energy	Object *(suggested answers in italics)*
Radio wave	least	*ping pong ball*
Microwave		*beach ball*
Infrared		*tennis ball*
Visible		*football, or basketball*
Ultraviolet		*football, or basketball*
X-ray		*baseball*
Gamma ray	greatest	*golf ball*

(Suggestion: Debrief and guide students. Allow students to articulate reasons for their choices. They may have different answers than expected, but the reasoning for their answers should indicate an understanding that the more energetic objects belong at the bottom of the table.

Additionally, you may wish to extend this discussion to include what variables affect the energy of each type of ball. In this model, the kinetic energy of the balls mimics the energy of light in different regions of the spectrum. Note that an object's kinetic energy depends on its mass and velocity (although students may also suggest the shape, composition, or geometry of the object). But the energy of light depends only on its wavelength, and not on its speed (since its speed is constant). Be careful that students recognize this feature of the model.

4. Review video chapter for Pause Points 4 and 5 ("What is X-ray Spectroscopy") in which Dr. Harrus discusses how finding out what is going on far away in space is like watching what type of ball comes out of a stadium.

5. Focus on the object that students chose to be like an X-ray. Ask:
- Would it do a great deal of damage to objects if moving quickly (at the speed of a car on the highway for example)?
- What are some things (processes) that might **cause** this object to be moving that fast? (For example, if you chose a football, a process that might cause a football to move as fast as a car might be that it was thrown or kicked).

Additional Resources:
The following resources are strongly recommended parts of this activity and may be used with the whole class or to differentiate instruction:

1. http://www.astrocappella.com/groove.shtml - The "High Energy Groove" from Astrocappella. Multiple intelligence theory brings us information and challenges. The "Groove" helps to bring a high quality musical twist to the topic of X-rays. From the "Groove" page, you can download the song (as an MP3), find a very basic lesson plan, and find extra resources on high-energy astrophysics.

2. http://heasarc.gsfc.nasa.gov/docs/xte/outreach/HEG/groovie.html - "The Groovie Movie." Adding visuals to the above song, the movie is worth taking 5 min of class time and showing. It can serve as a beginning to discussion or a closing activity that will leave students with a smile on their face. Several missions are highlighted in the movie. Here is a "cast list" of them:

Mission	Description
RXTE	The Rossi X-ray Timing Explorer (RXTE) observes the fast-moving, high-energy worlds of black holes, neutron stars, X-ray pulsars and bursts of X-rays that light up the sky and then disappear forever.
Chandra	Chandra allows scientists from around the world to obtain unprecedented X-ray images of exotic environments to help understand the structure and evolution of the universe.
Yohkoh	The Yohkoh satellite was an observatory for studying X-rays and gamma-rays from the Sun.
TRACE	TRACE, the Transition Region and Coronal Explorer, launched in 1998 aboard a Pegasus XL rocket. It is observing the Sun for the connection between its magnetic fields and the heating of the Sun's corona.
XMM-Newton	XMM-Newton is a joint NASA-European Space Agency (ESA) orbiting observatory, designed to observe high energy X-rays emitted from exotic astronomical objects such as pulsars, black holes and active galaxies.

2. http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html - "Imagine the Universe" page that is an introduction to the spectrum. It is a well-written, comprehensive treatment with graphics that are most helpful. Showing this to a whole class would allow for discussion of the graphics. Vocabulary is made more accessible through mouse-over definitions and explanations. This page includes links to a knowledge-based four-question quiz, a "cool fact" dealing with wave-particles, an online word search, a more advanced treatment complete with an online movie clip, and a list of additional resources. Each of these pages is valuable in its own way, and all can be used to create a lesson that is differentiated for all learners.

IV. Video Chapter 3 – Building the X-ray Spectrometer and the X-ray Telescopes

Lesson Plan

Focus for Viewing

This section of the video describes the microcalorimeter, the Dewar, the clean tent, and the production of mirrors for the X-ray Telescopes (XRTs). Invite students to share anything they already know about these topics. Tell students to pay close attention to the sequence about creating the mirrors, as they will later create a poster showing the sequence.

Before viewing this chapter of the video, distribute to the students the "Worksheet for Chapter 3" (page 61) This worksheet gives the following Focus for Viewing questions:

- Why does the microcalorimeter array have to be so cold?
- How is the microcalorimeter kept cold?
- How does a clean tent work?
- What do you think it would be like to work in a clean tent?
- What material is put on the outer surface of the metal foils in the telescopes?

Viewing Guide

This chapter begins at 16:27 and ends at 25:54. In the Chapters menu on the DVD, this chapter is called "Building the X-ray Spectrometer and the X-ray Telescopes." You may pause the video at the following Pause Points and guide the discussions given below. (Times noted are elapsed times from the beginning of the video.) In addition, each Pause Point has a separate clip that can be found in the Teacher Resources menu on the DVD. You may replay the clips as needed.

Pause Point 7 – Why So Cold?

Stop the video after Dr. Boyce talks about keeping the instrument cold, as the screen fades to a shot of the clean tent. (20:05)

- Discuss how cold the instrument is, compared to everyday things that students would find "cold" (e.g. ice cream or a snowy day). Make comparisons between what astronomers call "hot" or "cold" and what those words mean on Earth.
- Have small groups do a "round robin" activity. One student starts with a fact they remember from this portion. The next student adds another fact, and so on. Replay this pause point to check students' answers.
- Explain that the next section of the video shows the clean tent and the telescope mirror construction process.
- Resume playing the video.

Pause Point 8 – Manufacturing the X-ray Mirrors

Stop the video at the end of the mirror assembly sequence, after a gloved hand places a finished foil into a case. (25:50)

- Have the students discuss how a process that contains multiple steps gets done. What sort of planning needs to be done? What type of teamwork is necessary? For the assembly of the mirrors, what skills are necessary at each step? Can one person do all of it, or should different people do different steps?

Post-Viewing Activities

1. Discuss the Focus for Viewing questions.

2. Have small groups make posters that show the first steps involved in manufacturing the mirrors. Display the posters around the classroom.

3. Have students create additional questions about this chapter and ask them to the class.

4. Have students make a list of questions they are interested in that they think might be answered in the rest of the video.

Background:
Mirror Assembly Terms

NOTE: Words are listed in order of assembly, not alphabetically.

mirror
In the context of the Astro-E2 (Suzaku) X-Ray Telescopes (XRTs), a mirror is a fully functional telescope optic. The terms “mirror” and “telescope” are used here interchangeably.

foil
A foil is a thin, flexible sheet of metal. The thickness is usually expressed in thousandths of an inch (mils), or in microns or tens of microns. In the Suzaku (Astro-E2) X-Ray Telescopes, a foil is a single reflector element in any stage of fabrication from flat aluminum sheet to the formed and gold-coated reflector, cut to the final arc length. “Foil” is just jargon for “reflector element”, but more specifically a foil is the substrate, or backing, for the thin gold reflecting surface.

reflector
A reflector is a finished foil. The concave surface of the reflector has a smooth, shiny gold front surface from which X-rays will reflect. On Astro-E2, the telescope for the XRT has 1,344 reflectors. The four telescopes for the X-ray Imaging Spectrometer each have 1,400 reflectors.

mandrel
One definition of mandrel is a round object about which something can be shaped or cast. In the context of Astro-E2 XRTs, two types of mandrels are used, one for forming or shaping foils, and the other for surface replication. This second type of mandrel is used in the sense of casting a material over it. Gold is deposited onto the smooth replication mandrel, and then a foil backing or substrate is attached with epoxy. Later, the foil/epoxy/gold sandwich is removed from the mandrel, resulting in a smooth gold-coated reflector foil.

grazing incidence
In an optical telescope such as the Hubble Space Telescope, the light rays strike the reflector surface at or near 90 degrees from the surface; this is called normal incidence reflection. The field of X-ray optics employs a technique called grazing incidence reflection, in which a light ray hits the reflector surface at a very small angle up from the surface. For the XRTs, the angle of incidence of the X-ray photons to the reflectors is about 0.2 degrees at the inner, small-radius reflectors, and about 0.7 degrees at the outer, large-radius reflectors. The reflectors are thus nearly edge-on to the source of X-rays of interest.

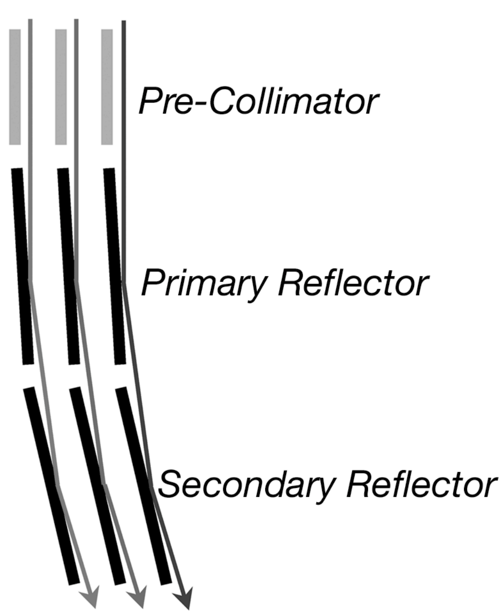
nesting
Because the reflectors of an X-ray mirror are nearly edge-on to the incident X-ray, the geometric area of the reflector is foreshortened to a tiny fraction of what it would be in normal incidence reflection. For this reason, X-ray mirrors use a system of multiple concentric reflectors, packing (or nesting) as many reflectors in the available space as possible. The number of reflectors that can be nested is limited by the thickness of the foil backings, and the structure required to keep the reflectors rigidly aligned with each other and the focal-plane instrument.

assembly
"Assembly" is a term that can represent an activity, such as the putting together of all of the various pieces of a telescope. "Assembly" can also represent the result of that activity; once the pieces of the telescope are put together, the result is called a mirror assembly.

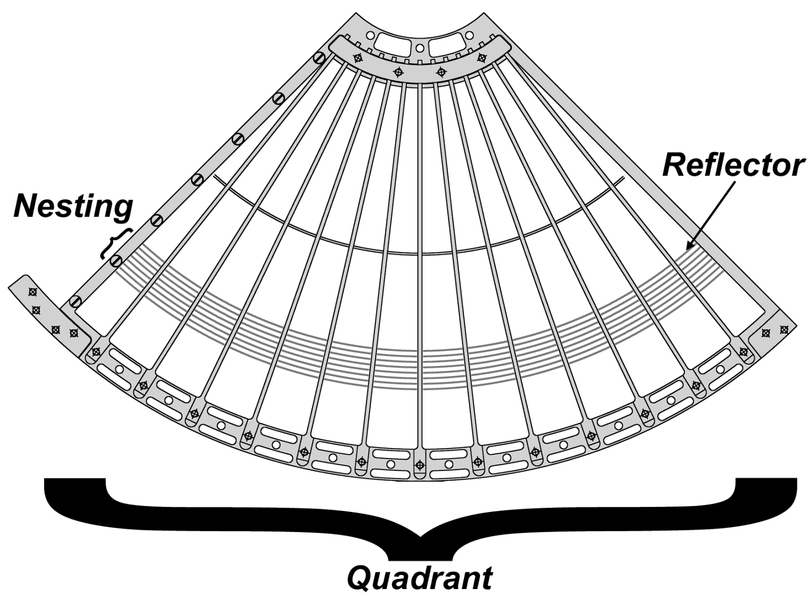
pre-collimator
A collimator is a device used to block light rays from outside of a prescribed viewing angle (off-axis light). The nested reflector foils of the Astro-E2 (Suzaku) telescopes provide a certain amount of collimation, since X-rays do not reflect well when they strike the back, uncoated surfaces of the foils. But even with this "natural" collimation, some photons that are not from our preferred viewing direction may strike the secondary reflectors without first striking the primaries, resulting in a small amount of erroneous data being collected. By placing a section of nested, non-reflecting foils above, and aligned with, the primary reflectors, we can block most of these off-axis X-rays from entering the X-ray mirror. This section is called the pre-collimator.

quadrant
A quadrant is simply a quarter of a circle. Traditional X-ray telescope mirrors, such as that on Chandra, use full-circle reflector shells; Astro-E2 (Suzaku) uses telescope mirrors that are assembled in quadrants first, and then four quadrants are bolted together to form a full mirror assembly.

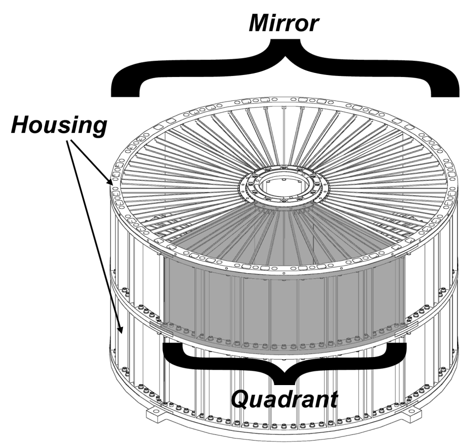
housing
The telescope mirror housing is the structure that provides a rigid structure to hold the nested foil reflector elements, and keep them in alignment. Each telescope mirror must provide for two reflections of the X-rays, a primary reflection and a secondary reflection. Consequently, there are a primary housing and a secondary housing, each of which occupies a quarter of a circle. The primary and secondary are bolted together, one on top of the other. This is a quadrant assembly, which can function as a quarter of a full mirror. Four quadrants are bolted together for a fully functional X-ray telescope mirror assembly.



The path of X-rays within the mirror. X-rays pass through the pre-collimator, reflect off the first ("primary") set of reflectors, then off the second ("secondary") set of reflectors, and then to the X-ray Spectrometer.



A quadrant of an Astro-E2 (Suzaku) telescope. An individual reflector and a portion of the nesting of reflectors are labeled. An entire quadrant has about 170 reflectors.



An Astro-E2 (Suzaku) mirror, showing the placement of one of the quadrants. Also shown are the upper primary housing and the lower secondary housing. Not shown is the pre-collimator, which would be placed on top of the primary housing.

Activity 2:
A Human Model for Grazing Incidence Angle
X-rays must hit a surface correctly to be focused.
This angle is shallow, critical, and called the grazing incidence angle.

A Human Model for Grazing Incidence Angles
Time required: 15-30 min with minimal teacher prep time
Objective:
- Relate different wavelengths of light to energy associated with photons of that light.
- Compare how photons of different energies are reflected or absorbed by a surface.
- Associate X-rays with high-energy photons.

Standards: See section 7 of the Introduction (p. 4)

Student Audience:
This activity is appropriate for both middle and high school classes in Physical Science, Introductory and/or Conceptual Physics, and General Physics.

Overview:
What is a "grazing incidence angle" anyway? It is a very important concept when considering how to get the X-rays that you want to detect to focus and be measured. In this module, we use a human reflective surface and photons of different energies (represented by different masses) to show that different photons may be absorbed or reflected, depending upon their energy. With this model, students will have a ball!

We will model grazing incidence reflection by using students as the "sea of electrons" provided generally by metallic bonding on the surface of a metal. The tossed ball is the photon of light. The tosser is the object giving off the photon. Thus, we have a model that should work especially well with kinesthetic students.

Materials:
Ping-pong ball
Golf ball
Tennis ball (or similar object)
Basketball or bowling ball or other large, massive ball
Optional: Several raw eggs
Piece of wood or other flat material to be used as a ramp
Note: Each of the lab/demos in this activity is arranged in modules such that they may be done individually or as a complete set. This will aid differences in teaching styles, time that can be devoted to this topic, lab equipment available, etc.

Grazing angles and dodge ball
Time: 10-15 minutes

Sequence of events:
1. Line up between 4 and 10 students shoulder to shoulder in a straight line, facing you.
2. Gently toss a ping-pong ball toward them. Allow them to toss it back at the same speed. Repeat this for a golf ball, and then a tennis ball.

3. Explain that each ball was tossed at a different speed. This means that as it approached them, they acted differently for each. Perhaps asking them to imagine a bowling ball now being tossed at them would induce them to agree that their reaction would be different! You may want to measure that you were 3 m from the line and ask how long it took the ball to travel from you to them (hopefully about a second!). This allows for an easy estimate of the speed of each object. Also, explain that they could toss the ball right back to you, modeling "reflection." By comparison, a mirror reflects (most) of the visible light that hits it.
Note: This models reflection of visible light. To model X-rays which carry more energy than visible light, we must either increase the mass or volume of our tossed ball. We will model this increase by increasing mass and discussing its effects, rather than velocity, which may confuse the issue. It is important to note that X-rays DO NOT MOVE FASTER than visible light, and that we are simply modeling the higher energy particle by increasing its mass. (All light travels in a vacuum at $v = c = 3.0 \times 10^8$ m/s)
4. Let's now model some X-rays. Consider using a basketball. Explain to the students in the line that to model an X-ray the basketball is going to be thrown at them in a random place as hard as possible (app. 30 m/s or 63 mph - just like dodge ball). OF COURSE – DO NOT ACTUALLY THROW THE BALL! Observe their responses. Ask them if they would catch it or move out of the way so that something behind them would catch it? Repeat this but now with a bowling ball. AGAIN, DO NOT ACTUALLY THROW THE BALL! (A bowling ball would only have to move 8 m/s or 18 mph, which is still a speed that would scatter pins and students!)
5. Highlight the major point of the activity: Though some types of light may be reflected, more energetic forms of light may go right through exactly the same material.
6. ***(Should be done as a teacher demonstration only!)***
To drive the point home and provide transition to the next major concept, explain that the raw egg actually will be rolled at the wall. Ask if any way can be imagined that the egg might hit the wall and not break. You may wish to prompt that different angles may be considered. This leads to consideration that there may be a "shallow enough" angle that it might not break. Ask for speculation as to what that angle might have to be. Experiment for them starting at angles of 1° from the wall, and making the angle greater until breakage occurs. You may use a board as a ramp to roll the egg down, thus obtaining the same speed for all rolls. You have just demonstrated the concept of grazing incidence angles.

7. **Closure:** Provide a K-W-L ("What I Know" - "What I Want to Know" - "What I Learned") activity for closure and extension. Since we are modeling some complex ideas with this activity, it is especially important to root out any misconceptions that may exist. Since this material applies to many areas that may be discussed in the future, students may develop connections to those areas in the "L" portion of the activity. You may want to do this activity as a "think-pair-share" type activity. Thus a concept map could be used instead of a column or paragraph summary of things learned.

V. Video Chapter 4 –
Overcoming Challenges and Moving On

<u>Lesson Plan</u>

Focus for Viewing

This section of the video describes some problems the Goddard Astro-E2 team had and how they solved them. It also shows the team packing up the finished instruments for shipment to Japan. The video concludes with footage of the successful launch of the satellite.

Before viewing this chapter of the video, distribute to the students the "Worksheet for Chapter 4" (page 62) This worksheet gives the following Focus for Viewing questions:

- Why does the telescope team keep testing at every stage?
- How would you approach a problem like the leak in the XRS Dewar?
- How did the team keep track of their schedule?
- Why was dry ice, rather than water ice, used for packing the telescope?
- Imagine you are on the Astro-E2 team. How would you feel when the telescope was all packed up to go to Japan?

Viewing Guide

This chapter begins at 25:54 and goes through the end of the video. In the Chapters menu on the DVD, this chapter is called "Overcoming Challenges and Moving On." You may pause the video at the following Pause Points and guide the discussions given below. (Times noted are elapsed times from the beginning of the video.) In addition, each Pause Point has a separate clip that can be found in the Teacher Resources menu on the DVD. You may replay the clips as needed.

Pause Point 9 – First Signs of Problems

Stop the video after Dr. Kelley discusses the leak. (27:25).

- Discuss the problem and how the team approached a solution. Why was the leak difficult to find? How did the team re-act to this problem?
- Explain that the next section of the video shows more about the leak problem and how the problem was solved.
- Resume playing the video.

Pause Point 10 – Another Set-Back and Getting on Track

Stop the video after Dr. Boyce discusses getting back on schedule and the XRS is being prepared for packing up. (33:00)

- Have students explain how the problem was solved. Discuss how the team handled this second problem.
- Tell students the next section of the video shows how the XRS was packed and sent to Japan. Ask them to look at the way the XRS was packed.
- Resume playing the video.

Pause Point 11 – Packing the XRS

Stop the video after the XRS is surrounded by dry ice. (34:28)

- Have students explain how the XRS was packed. Why was it packed this way?
- Tell students that the conclusion of the video discusses the future of Astro-E2, including its name change after launch (to Suzaku).

The conclusion of the video includes footage of the successful launch of Suzaku. Additional launch footage can be found on the DVD from the main menu, and an accompanying description of the launch is on page 43 of this guide. To follow the travels of the XRS between the United States and Japan from the point of view of the XRS, visit the XRS Road Trip: http://suzaku-epo.gsfc.nasa.gov/docs/suzaku-epo/science/instruments/xrs_roadtrip/xrs_roadtrip.html

Post-Viewing Activities

1. Discuss the Focus for Viewing questions.

2. Discuss these additional questions with the class:
   - What does the team's approach to problem solving tell you about them?
   - What can you learn from the team's approach to problem solving?

3. Have the small groups complete their "telescope assembly" posters from Chapter 3 using information from this chapter.

4. Have small groups each draw one scene from the video and explain it to the class.

5. Have students create additional questions about this chapter and ask them to the class.

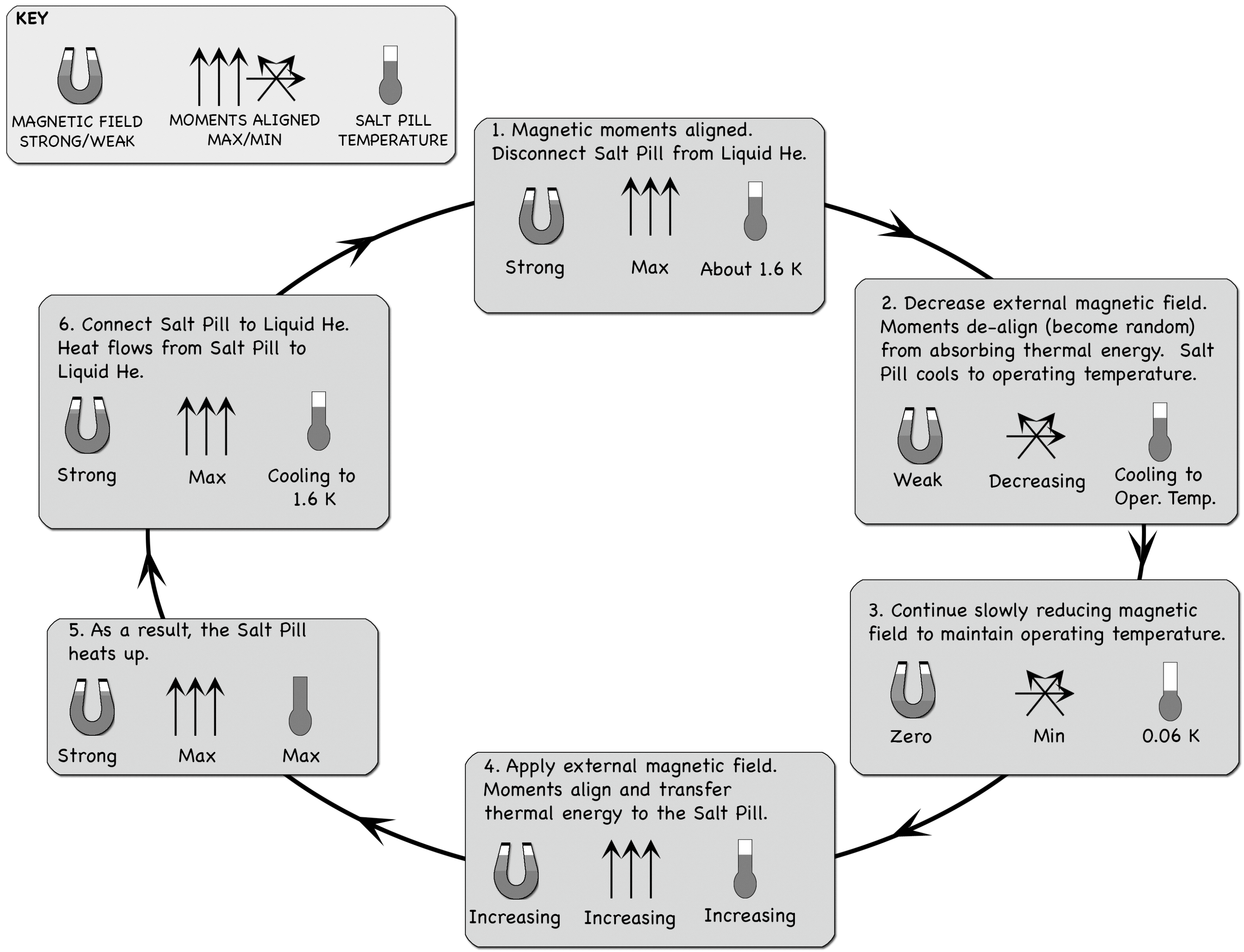
6. Have students make a list of questions they are interested in that they would like to have answered when they look at the Suzaku Learning Center web site:
http://suzaku-epo.gsfc.nasa.gov

Background:
How does an ADR work?

The microcalorimeter must be operated at a temperature of 0.06 K. Despite being out in space, the spacecraft is warmed by the sun, making it much too warm for the microcalorimeter. So the calorimeter needs to be in contact with something cold to keep it at its operating temperature. We often make an object cold by immersing it in something that's colder. But there's no material that's as cold as 0.06 K, so the microcalorimeter uses a device called an adiabatic demagnetization refrigerator (ADR). An ADR cools things by using the properties of heat and the magnetic properties of certain molecules.

Some molecules have naturally occurring internal magnetic fields, or "moments." Just like a tiny bar magnet, these molecules will align themselves with an external magnetic field. The random thermal motions of the molecules, on the other hand, tend to de-align them. The higher the temperature, the more they de-align. ADRs generally use certain types of salts for the molecules, because they have particularly large magnetic moments. The salt is contained in a cylinder, usually called a "salt pill." This salt pill is thermally connected to the object we want to cool (in this case, our microcalorimeter)

The diagram on the next page illustrates how the ADR works. The process starts (step 1) with the salt pill in a strong external magnetic field, and the magnetic moments aligned. Turning down the magnetic field (step 2) allows the magnetic moments to de-align, and absorb thermal energy. This cools the salt pill to the calorimeter operating temperature of 0.06 K. The strength of the external magnetic field is further decreased to maintain the operating temperature (step 3). After all the magnetic moments have de-aligned, the external magnetic field is turned on again (step 4). This re-aligns the magnetic moments, transferring thermal energy to the salt pill and increasing its temperature (step 5). The salt pill is then connected to a reservoir of liquid helium, which cools it to about 1.6 K (step 6). When the magnetic moments are aligned again and the salt pill is cooled to the liquid helium temperature, the process can be repeated (step 1).


KEY
MAGNETIC FIELD STRONG/WEAK
MOMENTS ALIGNED MAX/MIN
SALT PILL TEMPERATURE
1. Magnetic moments aligned. Disconnect Salt Pill from Liquid He.
Strong
Max
About 1.6 K
2. Decrease external magnetic field. Moments de-align (become random) from absorbing thermal energy. Salt Pill cools to operating temperature.
Weak
Decreasing
Cooling to Oper. Temp.
3. Continue slowly reducing magnetic field to maintain operating temperature.
Zero
Min
0.06 K
4. Apply external magnetic field. Moments align and transfer thermal energy to the Salt Pill.
Increasing
Increasing
Increasing
5. As a result, the Salt Pill heats up.
Strong
Max
Max
6. Connect Salt Pill to Liquid He. Heat flows from Salt Pill to Liquid He.
Strong
Max
Cooling to 1.6 K

Activity 3:
Dry Ice Inspired Problems
Dry ice is used to keep some things very cold.
How cold is it? How much to use? How do we figure it out?

A "cool", traditional problem set for high school chemistry and physics.
Time required: If done entirely in class, approximately 60-90 min, or about the same as a homework assignment.
Objective:

- Identify the properties, processes and concepts involved in shipping items that must remain cold.
- Apply the law of conservation of energy to instances of temperature and phase change.

Standards: See section 7 of the Introduction (p. 4)

Student Audience:
This activity is appropriate for high school general and advanced science students in courses such as College Prep Physics, AP Physics and Chemistry. Learners who are in 11th or 12th grade science and math classes would get the most out of this exercise.

Overview:
Suzaku is indeed the "coolest X-ray telescope" ever made, but keeping it cool is a challenge! In the video, we learn that dry ice was used to keep the XRS cold as it was transported from the NASA/Goddard Space Flight Center in Greenbelt, MD to Uchinoura, Japan for launch on July 10th, 2005. How do scientists know how much dry ice to use, and what are the properties of dry ice that make it a compelling choice to use in keeping instruments cold?

This activity highlights some of the heat transfer principles at work, and does so conceptually and then quantitatively. Added to the activity is a "bonus" module in creating liquid water that is colder than ice, that is, below 0° C. Feel free to use some of the activity as a "basic" lesson and other parts as extension. And no matter what, KEEP YOUR COOL!

Below is an answer key for the questions on the student worksheet.

Warm-up:
View the video from 33:00 to 34:30 (or Pause Point 11). What is the chemical name for dry ice? What special properties make dry ice more useful than regular ice (water ice) in some circumstances? Highlight that dry ice is colder and vaporizes. It never goes through being a liquid, but immediately becomes a gas. This process is known as "sublimation."

Reference Data:
For the following problems, some of the information that follows is critical. Unless noted, all information is given for STP.
Density of dry ice as a gas at 298 K: 1.833 kg/m^3
Density of dry ice solid at 194 K: 1562 kg/m^3
Density of air: 1.29 kg/m^3
Heat of sublimation for dry ice: 199.0 kJ/kg
Heat of fusion for water: 333 kJ/kg

Specific heat of water (liquid): 4186 J/kg K
Specific heat of air: 1030 J/kg K
Sublimation temperature @ 1 atm: 194 K
1 kg = 2.21 lb

Problems:
Dr. Kevin Boyce mentions that 450 lb of dry ice is used for cooling as transportation occurs from the Goddard Space Flight Center in Greenbelt, Maryland to Japan. (Answers are given in parentheses.)

1. What is the mass in kg of this amount of dry ice? (204 kg)
2. Estimate – How many students in your class would it take to lift this much dry ice? (Answers will vary. A good answer for a typical classroom would be 4 people lifting about 50 kg or about 110 lbs. Consider that the world record for a weightlifter's snatch is 213 kg. For more perspective on these human extremes, see http://www.iwf.net/wrec/world.html)
3. What volume is occupied by the solid dry ice? (0.131 m^3)
4. Assuming the assembly to be shipped is 1 m3, what must the volume of the shipping crate be to comfortably hold both the cryostat and the dry ice solid? (Assuming a little "breathing room" of about 10% in excess of volume of cryostat and dry ice, 1.24 m^3. This may lead to a good discussion about leaving extra room in design consideration.)
5. Create dimensions for a cube to illustrate how much space would be taken up by the solid dry ice. (1.08 m^3)
6. What volume is occupied by the gaseous carbon dioxide? (111 m^3)
7. Calculate dimensions for a cube to illustrate how much space would be taken up by gaseous carbon dioxide. (4.81 m^3)
8. What is the ratio of the two volumes that were just calculated? (The volume of the gas is 847 times greater than the solid.)
9. What design advice might you give regarding the shipping crate…should it be airtight? Justify your answer. (Consider the pressure exerted by the gas. Using the ideal gas law, the resulting pressure is 87000 kPa or 860 atm rounded to 2 sig. digits. Even allowing for the extra 10% in problem 4 above, this increase in pressure could have negative, disastrous results. Thus, it would be a good idea to allow for some "breathing" in the crate, allowing the carbon dioxide gas to leave the crate.)
10. How much heat would have to be absorbed by the dry ice for all of it to sublimate? (40,600 kJ)

    Go to http://suzaku-epo.gsfc.nasa.gov/docs/suzaku-epo/science/instruments/xrs_roadtrip/archive.html#2004_03_10 and read the passages for 3/10/2004 through 3/15/2004. Note some of the important places and times.

11. What mass of air would be needed to cause the complete sublimation of the dry ice? (Assume that the air is refrigerated during the entire trip and is at 283 K. Assume that it will cool to 273 K when exchanging heat with the sublimating ice.)
    (Ans: 3940 kg)
12. What volume would this mass of air occupy? (3060 m^3)
13. If all of the air in the plane's cargo holds were to cool as described, would it sublimate all of the dry ice? Justify your answer. (The cargo capacity for a Boeing 747 is on the order

of 100-200 m^3. A fair assumption is that the volume of the cargo hold is 2-3 times greater. Thus, we do not have to worry about total sublimation in the plane, even if air is refreshed during two or three layovers. Source: http://www.plane-spotter.com/Aircraft/Boeing/747.htm)

14. If water were in direct contact with the dry ice, what mass of liquid water at 0° C would turn to water ice at the same temperature? (121 kg – a big ice cube!)
15. Suppose the water was at room temperature (298 K). Repeat the question above, considering that the temperature of the water must first be reduced to its freezing point. (93 kg – this problem involves both using a temperature change and a phase change)

You may wish to expand upon the lines of questioning.

STUDENT WORKSHEET

Name:______________________________________ Class:___________________

Date:___________________________ Period:____________

BEFORE YOU DO ANYTHING: View the video from 33:00 to 34:30 (Pause Point 11. What is the chemical name for dry ice? What special properties make dry ice more useful than regular ice (water ice) in some circumstances? Dry ice never goes through being a liquid at standard temperature and pressure (STP), but immediately becomes a gas. This process is known as "sublimation."

REFERENCE DATA BRIEFING:

For the following problems, some of the information that follows is critical. Unless noted, all information is given for STP.
Density of dry ice as a gas at 298 K: 1.833 kg/m^3
Density of dry ice solid at 194 K: 1562 kg/m^3
Density of air: 1.29 kg/m^3
Heat of sublimation for dry ice: 199.0 kJ/kg
Heat of fusion for water: 333 kJ/kg
Specific heat of water (liquid): 4186 J/kg K
Specific heat of air: 1030 J/kg K
Sublimation temperature @ 1 atm: 194 K
1 kg = 2.21 lb

Dr. Kevin Boyce mentions that 450 lb of dry ice is used for cooling as transportation occurs from the Goddard Space Flight Center in Greenbelt, Maryland to Japan.

1. What is the mass in kg of this amount of dry ice? _______
2. Estimate – How many students in your class would it take to lift this much dry ice? (Consider going to http://www.iwf.net/wrec/world.html to help with and assumptions)
   ____
3. What volume is occupied by the solid dry ice? _______________
4. Assuming the assembly to be shipped is 1 m^3, what must the volume of the shipping crate be to comfortably hold both the cryostat and the dry ice solid? (How much extra "breathing room" should you leave?)
   ____
5. Create dimensions for a cube to illustrate how much space would be taken up by the solid dry ice.
   ____
   ____
6. What volume is occupied by the gaseous carbon dioxide?
   ____
7. Calculate dimensions for a cube to illustrate how much space would be taken up by gaseous carbon dioxide.
   ____

8. What is the ratio of the two volumes that were just calculated?
9. What design advice might you give regarding the shipping crate…should it be airtight? Justify your answer. (Consider the pressure exerted by the gas. Perhaps apply a gas law!)
10. How much heat would have to be absorbed by the dry ice for all of it to sublimate?

Go to http://suzaku-epo.gsfc.nasa.gov/docs/astroe_lc/science/instruments/xrs_roadtrip/archive.html#2004_03_10 and read the passages for 3/10/2004 through 3/15/2004. Note some of the important places and times.

11. What mass of air would be needed to cause the complete sublimation of the dry ice? (Assume that the air is refrigerated during the entire trip and is at 283 K. Assume that it will cool to 273 K when exchanging heat with the sublimating ice.)
12. What volume would this mass of air occupy?
13. If all of the air in the plane's cargo holds were to cool as described, would it sublimate all of the dry ice? Justify your answer. (Check out: http://www.plane-spotter.com/Aircraft/Boeing/747.htm)
14. If water were in direct contact with the dry ice, what mass of liquid water at 0° C would turn to water ice at the same temperature?
15. Suppose the water was at room temperature (298 K). Repeat the question above, considering that the temperature of the water must first be reduced to its freezing point. (Note: this problem involves both using a temperature change and a phase change)

VI. Capstone Activity

PUTTING IT ALL TOGETHER
Now It's Your Turn – You are the Astrophysicist!!!

Time Required: Two or three 50 minute sessions. Prep time: about 15 min.
Objectives:

- Analyze and interpret a spectrogram
- Identify the unknown elements in a substance or object based upon graphical data
- Compare graphical outputs, taking a position as to which is most useful
- Appreciate the need for continued improvement of measurement instruments
- Relate classroom work to an authentic piece of scientific literature

Overview:

To the reader: This exercise was written before the loss of liquid helium cooling the XRS. Up to that time, the XRS had taken preliminary calibrating measurements and worked perfectly. All references below to the working XRS on Suzaku should be viewed as if the XRS were still functioning or had continued to function properly. This exercise should continue to be effective in your classroom even though "real" XRS data will not be available. The important ideas here are that anything built for space must be tested so that instruments will withstand both an unforgiving environment AND a launch from 0 to 17,000 mph in 3 min. Most instruments sent to space are first-time, one-time instruments, and the luxury of testing several models to find the one that works, as one may do with a car design, rarely exists. The XRS represents several years of a new design for a type of instrument that allows us to view the universe in a way that is orders of magnitude better than before. Students should understand that this is a challenging, exciting form of problem solving where the stakes are high and the knowledge gained is on the cutting edge of science!

Lastly, the other four instruments on Suzaku continue to function as of this printing, and will serve the scientific community as expected. The data collected by them is different than that from the XRS, but valuable as well.

For more details, visit *http://suzaku-epo.gsfc.nasa.gov/docs/astroe_lc/news/xrsend.html*.

What will some scientists do with the data from Suzaku? The same thing students are about to! In this exercise, students will explore authentic and simulated data and develop an appreciation for the spectral analysis of any unknown substance. As such, this is an activity that has applications in chemistry, physics, astronomy and mathematics, and can be broadly used in a curriculum, and across curricula. In this case, the object under study is heavily ionized which allows for large transitions in energy for electrons. Specific transitions are read as peaks on the spectrogram. Additionally, students will explore an authentic piece of scientific work.

Spectral analysis is an important skill in all branches of science. Students will be asked to examine and analyze spectra from a past mission (ASCA) and compare it to simulations of data from future missions, including Suzaku. A thorough comparison will show better data from each successive generation of spacecraft. (There will be much more accuracy with Suzaku) Finally, they will be given spectra from the next generation of X-ray telescope (currently Constellation-X) and asked to determine what elements are present. (There will be even better resolution with Constellation-X). Students will Compare and contrast their findings as a class. Finally, students will be exposed to the actual scientific paper from which the ASCA data was taken.

Standards: See section 7 of the Introduction (p. 4)

Materials:

- "Cas A-East XRS Simulated" data plot (p. 35)
- Simulated ASCA, Astro-E2 and the "Next generation x-ray telescope" spectra of Tycho supernova remnant (pp. 37-39)
- Chart of X-ray lines corresponding to elements (p. 36)
- "X-ray Emission-Line Imaging and Spectroscopy of Tycho's Supernova Remnant" by U. Huang and E. Gotthelf available in .pdf format at http://suzaku-epo.gsfc.nasa.gov/docs/astroe_lc/education/video/video.html
- Student worksheet (page 40)

Warm Up:

- Ask students to graph a rough but somewhat accurate plot of skin height vs. distance across their finger (leftmost point = 0 mm)…in other words, plot their fingerprints. Accept most answers and discuss points such as shape of the graph, units and scales, and most importantly, similarities and differences between the individual shapes of the graphs, emphasizing that though each is generally similar, the differences are enough to identify you from the other 6 billion or so people on earth!
- The website http://mo-www.harvard.edu/Java/MiniSpectroscopy.html provides a mini lesson in visible spectroscopy. Students are encouraged to look at this site and use the activity as a starting point for your lesson, either as a warm up or a prelude to the warm up described above.
- Distribute the simulation of Cas A-East (Cassiopeia A – a strong X-ray source) XRS data and the "Energies of Elemental Spectral Line Features" page. Ask students to locate and label any peaks on the data graph that correspond to values on the spectral line features table.

Procedure:

1. Referring to the "Energies of Elemental Spectral Line Features" table, briefly explain that most substances and objects have similar "fingerprints" characterized by their spectra (some students may remember this from a chemistry course). Spectral analysis has been used to identify the composition of elements and compounds for decades. At lower temperatures, transitions can be detected at lower energy regions of the spectrum. At high temperatures, elements are heavily ionized and stripped of all but a few electrons. These transitions are more dramatic and energetic, and give rise to X-rays. So if we want to find out what elements are present in extreme conditions, we must study the X-ray spectrum of the object. Project or somehow show the picture of Tycho's Supernova. An excellent source for the image and an explanatory caption is http://chandra.harvard.edu/photo/2002/0005/index.html.
   As this is shown, explain that today's exploration is in finding out what elements exist in the remnant.
2. Distribute the ASCA simulated data. Ask students to identify the 5-10 most prominent peaks. Ask if any of the peaks correspond to any of the energies on the chart. Can any of the elements on the chart be identified? If so, which? Clearly identifiable should be Si (1.865 keV), S (2.461 keV), Ar (3. 410 keV), Ca (3.930 keV), and Fe (6.701 keV but broad). Where were these atoms (elements) created? (Note that supernovae play a role

in forming the heavier elements. Some percentage of these detected elements came from the actual event observed in 1572).

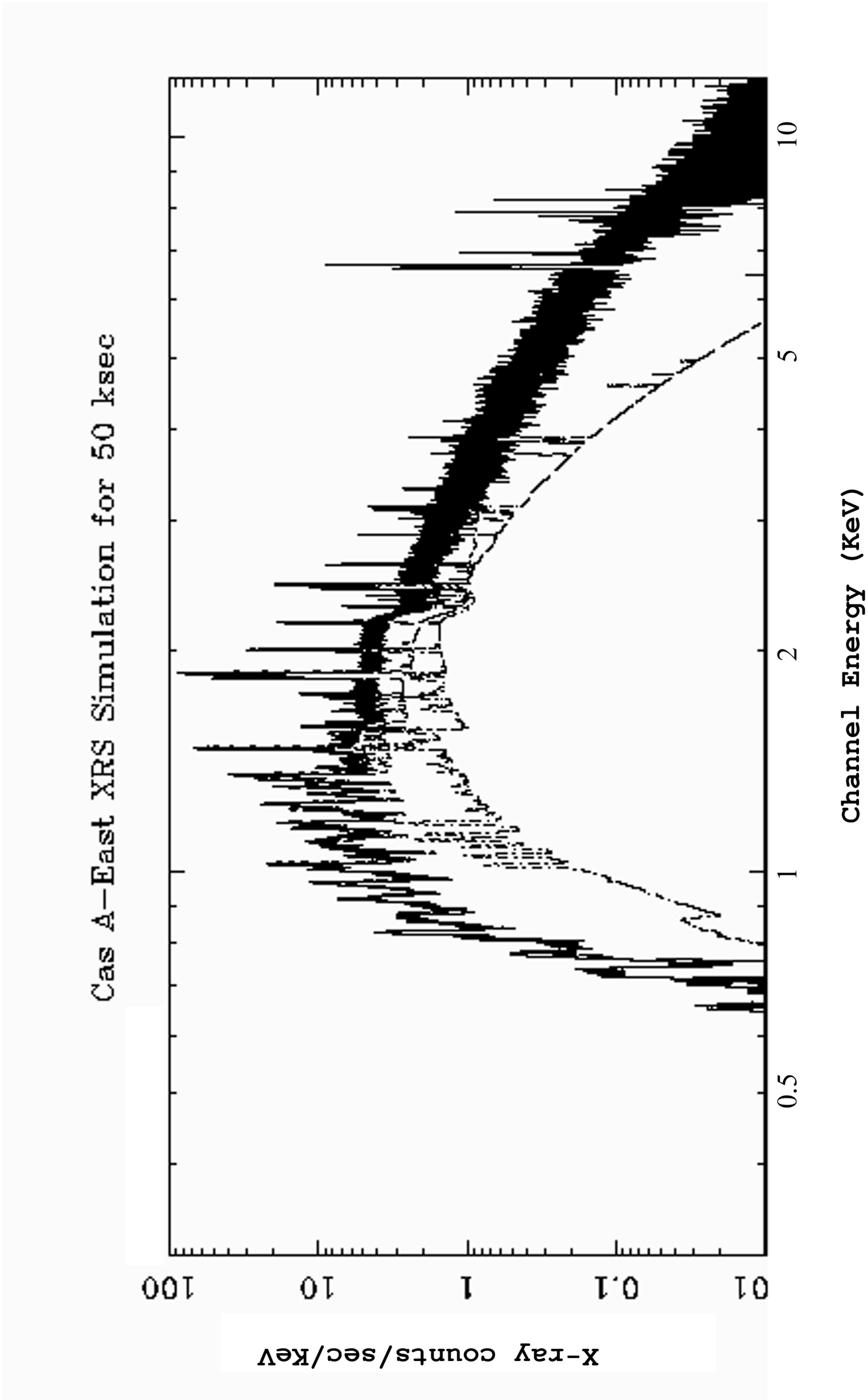
3. Now distribute the other two data graphs: Astro-E2 data and Constellation-X (the "Next generation X-ray telescope") data. Ask students to immediately identify similarities and differences (give them no more than 3-5 minutes). They should note small differences in the scale on the y-axis, and the increase in the resolution which they may describe as more "detail", more "peaks and valleys", etc. In looking at the Suzaku data, how many Si lines can be clearly seen now? What about S lines? Ar lines? Reinforce the term "resolution" at this point by explaining that Astro-E2 and Constellation-X (the next generation X-ray telescope) will provide higher resolution data that ASCA. Ask for conclusions as to why the graphs are better (better instruments on each later spacecraft). Also, what did we find from the analysis of this graph that we did not know from looking at the picture that came from Chandra? Highlight that the improvement in instrumentation translates into better data.
4. Assessment:
    1. How are identifying elements in a supernova like identifying a person using their fingerprints?
    2. Sketch a graph in which Si, Ar, and Fe appear to be present in a spectrogram of a distant object. Correctly label each scale, and it should be obvious whether an axis is linear or log.
    3. What advantage(s) do we find with the data of each successive spacecraft sent to study objects that have been studied on the past?
    4. Name at least 3 ways that the paper that was written by scientists different than your laboratory write-ups/products?

Extension Activities:

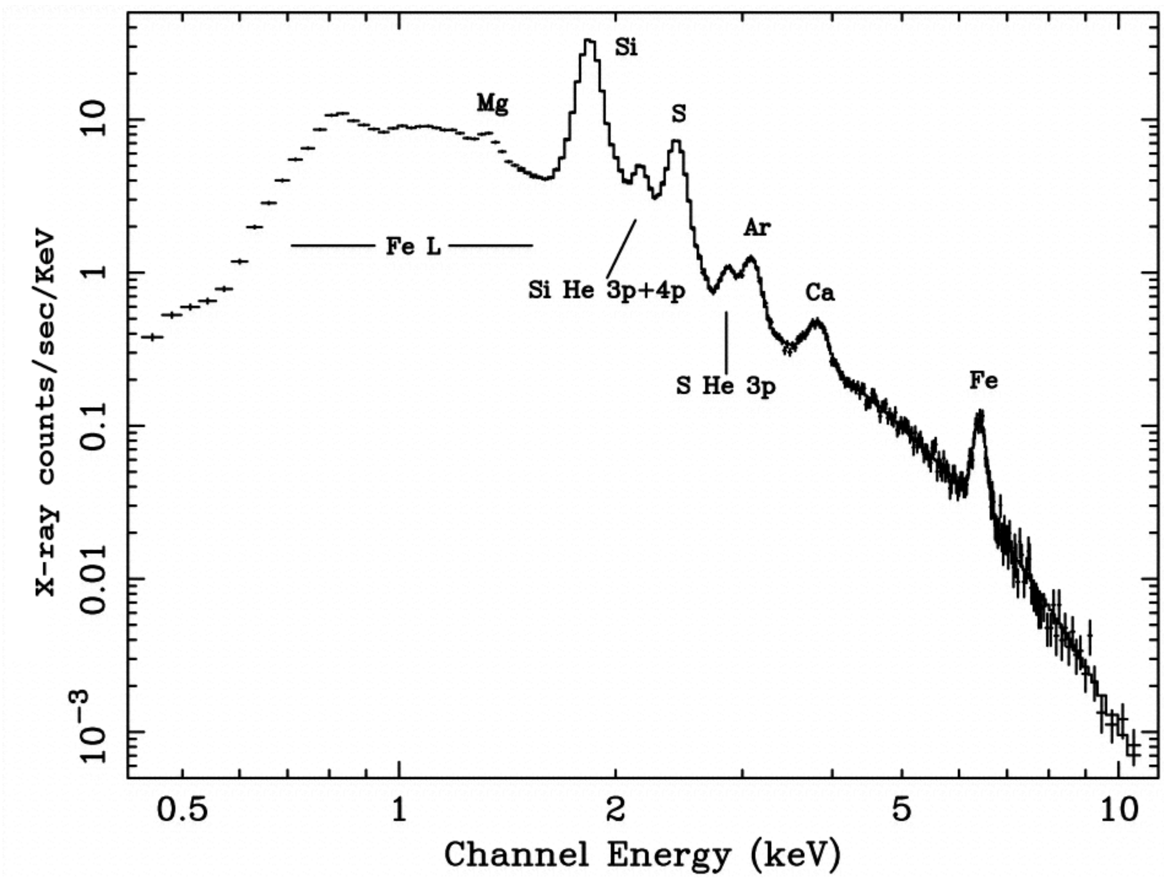
1. Einstein and EXOSAT were missions of the late 70s and early 80s that took earlier generation data of many supernovae remnants. Students should navigate to http://suzaku-epo.gsfc.nasa.gov/docs/objects/snrs/casa_spectra.html and also click on the link to the "Einstein SSS" data in the first sentence http://suzaku-epo.gsfc.nasa.gov/docs/objects/snrs/snrs_spectra.html). How are the conclusions from the above activity either supported or not supported by the data and discussion at these two web pages?
2. Distribute, or have students access, "X-ray Emission-Line Imaging and Spectroscopy of Tycho's Supernova Remnant" which is available at http://Suzaku-epo.gsfc.nasa.gov/docs/astroe_lc/education/video/video.html. This is an authentic work that appeared in "The Astrophysical Journal" in 1997. Students should skim the paper, and pay attention to its structure and familiar images. This is an excellent example of real work done by real astrophysicists and is the type of work that will be built upon by Suzaku**.** How does the actual graph in the paper compare to the ASCA data that they used a few minutes ago? How many references are given in the bibliography?
3. Where can you find "real" papers on a scientific topic of interest? Try http://arxiv.org/ which is a warehouse of many papers that are published. Have students use the search feature by first selecting a specific area of science. "Astrophysics" is the first listing and worthy of exploration. Click on the word "find" and this will take you to a typical search screen. You might first try to search some of the work of a couple of scientists in the video. Type in "Harrus" for author and note the specific papers that Dr. Ilana Harrus has contributed to. It may be interesting to look at "An X-ray study of the supernova remnant G18.95-1.1" and examine page 16 which has actual ASCA data from this supernova

remnant. Note the similarities and differences between this data and that viewed in the activity. (For Dr. Boyce, include his first name initial: “K Boyce” and search his results.)

4. Perform a comparative research study on generations of spacecraft. Research EINSTEIN, EXOSAT, ASCA, and Suzaku, and detail the significant differences between them. See http://heasarc.gsfc.nasa.gov/docs/heasarc/missions/alphabet.hml. How do the proposals for Constellation-X differ? Instead of working with X-ray instruments, choose another type, such as IR, and find at least 3 IR satellites that have studied regions of space over at least two decades.
5. This may be used as an extra credit homework assignment or teachable moment: Why are many radio and visible light telescopes based here on the surface of the Earth, but other telescopes are sent into space? Two good reasons are escaping atmospheric scattering and some wavelengths of light don’t penetrating the atmosphere at all!



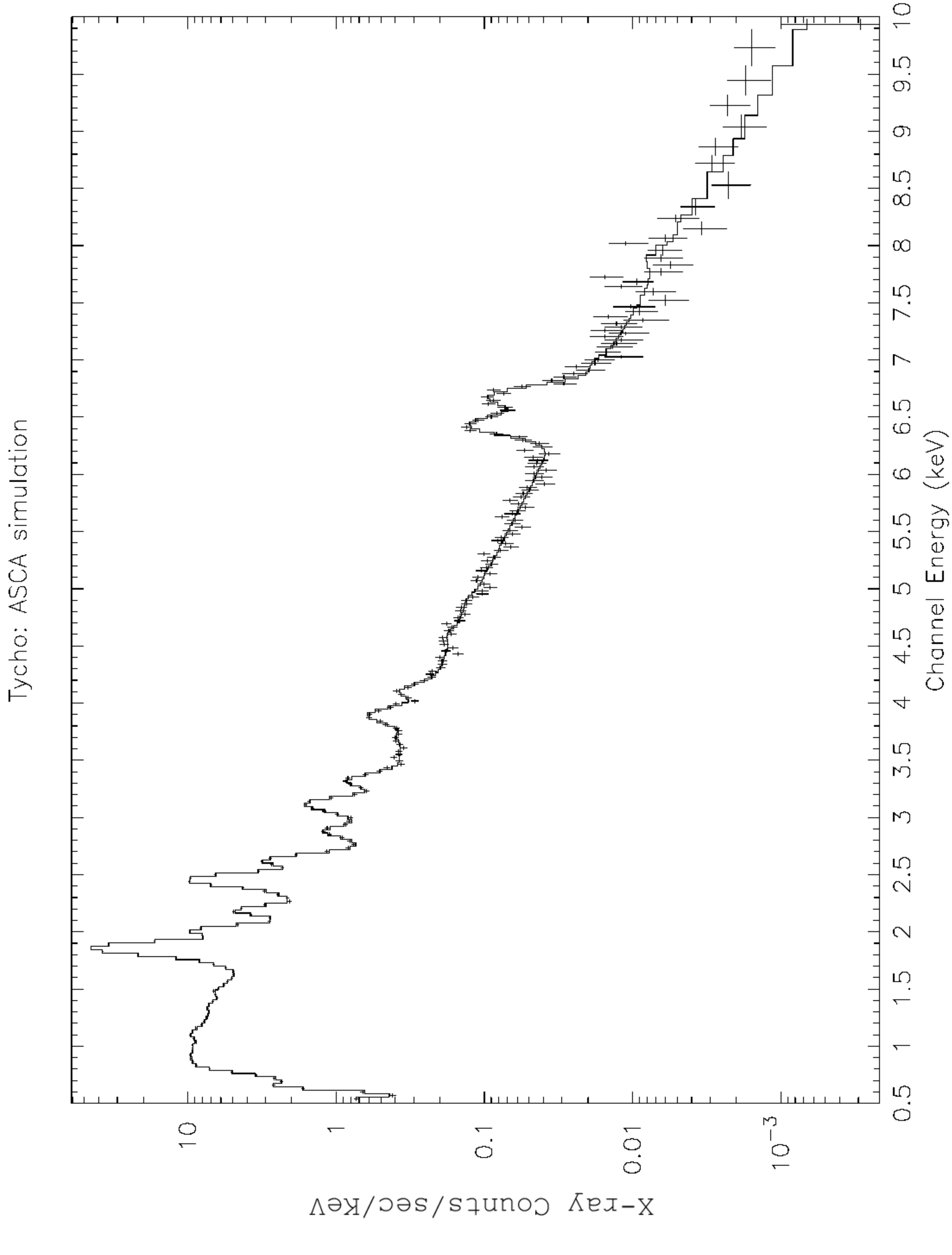
Cas A—East XRS Simulation for 50 ksec
Channel Energy (KeV)
X-ray counts/sec/KeV
0.5
1
2
5
10
100
10
1
0.1

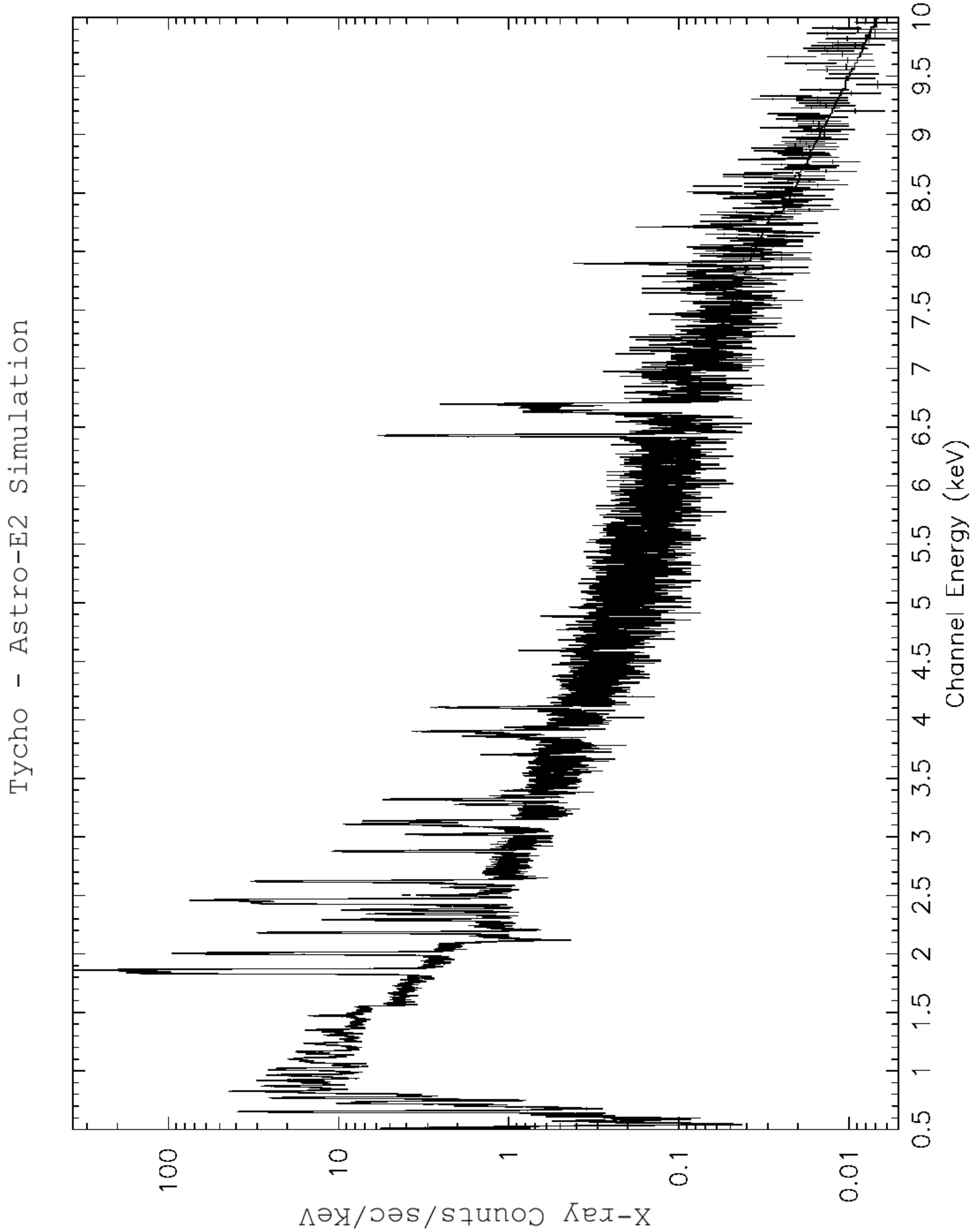


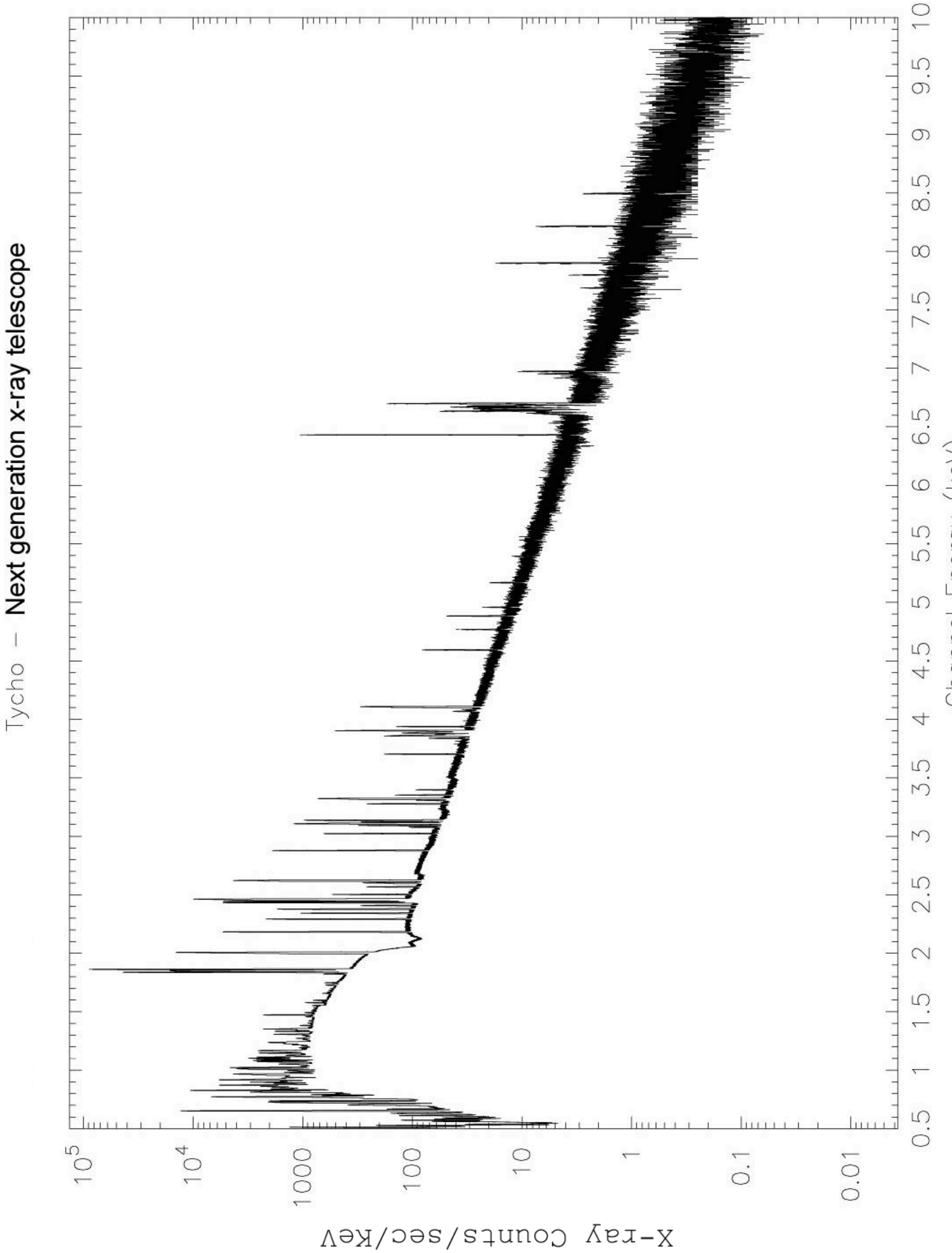
Reference (normalized plot) showing peaks, elements and correlations with table below.

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


Tycho: ASCA simulation
X-ray Counts/sec/KeV
10
1
0.1
0.01
10^{-3}
Channel Energy (keV)
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10


Tycho - Astro-E2 Simulation
X-ray Counts/sec/KeV
Channel Energy (keV)


Tycho — Next generation x-ray telescope
X-ray Counts/sec/KeV
10^5
10^4
1000
100
10
1
0.1
0.01
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
Channel Energy (keV)

Student Worksheets for Capstone Activity

Name:____ Date:_____________

Class:_________________________ Section:___________

Warm Up:

- Graph a rough but somewhat accurate plot of skin height vs. distance across your finger (leftmost point = 0mm)…in other words, plot your fingerprints.

- Now look at the website http://mo-www.harvard.edu/Java/MiniSpectroscopy.html. Read the material and examine the different spectra.

- Cassiopeia A is the remnant of a supernova explosion and a strong X-ray source. Look at the simulation of Cas A-East XRS data and the "Energies of Elemental Spectral Line Features" page. Locate and label any peaks on the data graph that correspond to values on the spectral line features table.

Procedure:

1. Refer to the "Energies of Elemental Spectral Line Features" table. Most substances and objects have "fingerprints" characterized by their spectra (you may remember this from a chemistry course). Spectral analysis has been used to identify the composition of elements and compounds for decades. At lower temperatures, transitions can be detected at lower energy regions of the spectrum. At high temperatures, elements are heavily ionized and stripped of all but a few electrons. The transitions are more dramatic and energetic, and give rise to X-rays. So if we want to find out what elements are present in extreme conditions, we must study the X-ray spectrum of the object. View http://chandra.harvard.edu/photo/2002/0005/index.html. How could we use X-rays to find out the composition of this object?

2. Obtain the ASCA simulated data. Identify the 5-10 most prominent peaks. Can any of the elements on the chart be identified? If so, which? Clearly identifiable should be Si (1.865 keV), S (2.461 keV), Ar (3. 410 keV), Ca (3.930 keV), and Fe (6.701 keV but broad).

3. Now obtain the other two data graphs: Astro-E2 data and the "Next generation X-ray telescope" data. Identify similarities and differences.

   In looking at the Astro-E2 data, how many Si lines can be clearly seen now? What about S lines? Ar lines? Why do the graphs get "better?"

   What did we find from the analysis of this graph that we did not know from looking at the picture that came from Chandra?

4. Assessment:
   a. How are identifying elements in a supernova like identifying a person using their fingerprints?

   b. Sketch a graph in which Si, Ar, and Fe appear to be present in a spectrogram of a distant object. Correctly label each scale, and it should be obvious whether an axis is linear or log.

   c. What advantage(s) do we find with the data of each successive spacecraft sent to study objects that have been studied on the past?

   d. Name at least 3 ways that a scientific paper is different than your laboratory write-ups/products?

Extensions:

1. Older generation analysis of another astronomical object: Einstein and EXOSAT were missions of the late 70s and early 80s that took earlier generation data of many supernovae remnants. Navigate to http://suzaku-epo.gsfc.nasa.gov/docs/objects/snrs/casa_spectra.html and also click on the link to Einstein SSS data in the first sentence (http://suzaku-epo.gsfc.nasa.gov/docs/objects/snrs/snrs_spectra.html). How are the conclusions from the above activity either supported or not supported by the data and discussion at these two web pages?

2. Obtain "X-ray Emission-Line Imaging and Spectroscopy of Tycho's Supernova Remnant." This is an authentic work that appeared in "The Astrophysical Journal" in 1997. Skim the paper, and pay attention to its structure and familiar images. This is an excellent example of real work done by real astrophysicists and is the type of work that will be built upon by Suzaku. How does the actual graph in the paper compare to the ASCA data that you used a few minutes ago? How many references are given in the bibliography?

VII. Appendix A – Launch Footage Description

This description of the launch of Astro-E2 (Suzaku), written by Dr. Kevin Boyce (who was present in Japan for the launch), is designed to accompany the launch footage available on the DVD. Dr. Boyce's essay explains the sequence of events during the launch, and also gives you a taste of what it would be like to be present for a satellite launch.

"nijyuu-go... nijyuu-yon..." ("25... 24...")
The rocket is on its launcher, hanging from the underside of the launch rail by means of a few small cogs on the side. Beneath the rocket is a cloud of spray where cooling jets have begun squirting water. This water will boil when the rocket fires, absorbing some of the heat that would otherwise destroy the concrete flame diverter.

"jyuu-go... jyuu-yon..." ("15... 14...")
The Solid Propellant Gas Generator (SPGG) is fired. This is a small solid rocket within the rocket, whose exhaust gasses power the hydraulic pumps for the nozzle steering system. These exhaust gases create the large cloud of black smoke at the bottom of the rocket.

"jyuu-san..." ("13...")
We switch to the rocket-cam view. This is a view from a camera mounted on the side of the rocket (the camera is actually inside, looking out through a tiny prism on the side of the rocket). The black plume from the SPGG is clearly visible.

"nana... roku..." ("7... 6...")
That's a lot of exhaust from the SPGG, isn't it!

"san... ni... ichi... zero"
This is it! Everyone in the control room is focused on their job. Actually, in the satellite control room there's nothing to do, because there's nothing we can do. The rocket team is monitoring the rocket's progress and the range safety team is standing by to blow up the rocket if it strays outside its predefined airspace, but at this point the satellite is just along for the ride.

The XRS instrument, for instance, isn't even powered. All we can do is watch the video of the rocket, hoping to see a nice smooth trajectory.

The roar reaches us. The rocket team is in a concrete bunker very close to the launch tower, but the satellite control room is about a mile away, so it's a few seconds before we hear the sound of the rocket. But boy is it loud when it gets there. The whole room rattles and shakes. The control room is directly beneath a 30 m diameter radio antenna, which weighs 180 tons and is built to survive a Category 5 hurricane. So if the room is rattling, you know something big is happening.

12:30:15 (time of launch)
By this point the rocket has reached the level of the clouds, so the view switches to a different camera. Fortunately the weather is only partly cloudy, so the rocket is visible from one camera or another. Southern Japan in August is tropical, and quite hazy, which cuts down the visibility. Watch the rocket climb through additional layers of clouds.

00:20 (time since launch)
Back to the rocket camera. You can see the small black plume of smoke from the exhaust of the SPGG as well as the bright yellow plume of the rocket itself. Watch how fast the clouds fade into the distance. The Japanese announcer is counting up the seconds since launch.

We switch back to the ground-based camera to see mainly the rocket plume. This is what we would expect, since the rocket is already many miles away, and of course with the rocket end still pointed at the launch site.

00:51
Back on the rocket camera now, the blinking icon indicates where the camera is on the rocket. The first stage of the rocket is not shown in the icon; it represents the second and third stages.

01:15
"Nanajyuu-go" ("75" seconds). The first stage separates from the rest of the rocket in a blinding flash, and the second stage begins firing. For those of us at the first ASTRO-E launch, this is a great relief. The first stage, which failed last time, appears to have worked perfectly. Our Japanese colleagues, who are in close communication with the rocket team, give us the thumbs-up.

At this point we realize that a minute and a half has passed and we really should start breathing again.

02:30
The second stage begins to burn out, on schedule. Everything is still looking good.

02:34
The rocket begins rolling, then pitching to the correct attitude for orbital insertion.

02:36
As the second stage burns out, the rocket begins pitching so that it's parallel to the ground. It's now above the atmosphere, so it's time to stop thrusting upward and start pushing purely sideways. The upward motion of the rocket is just to get above the atmosphere; it's the sideways change in velocity ("delta-v") that actually puts the satellite into orbit. Most of this delta-v will be provided by the third stage.

03:00
We switch to a split view, showing two cameras looking up at the third stage and satellite, which are covered by the nose faring. The one on the right is completely dark while the nose faring is on.

03:06
The nose faring is jettisoned. It splits down the middle like a clamshell and falls away to the sides, allowing light onto both sides of the third stage. The spacecraft is now exposed directly to space.

The right half of the image shows the black outer edge of the third stage motor, while the left shows some of the support structure. Because the two cameras aren't directly opposite each other, the view is somewhat confusing.

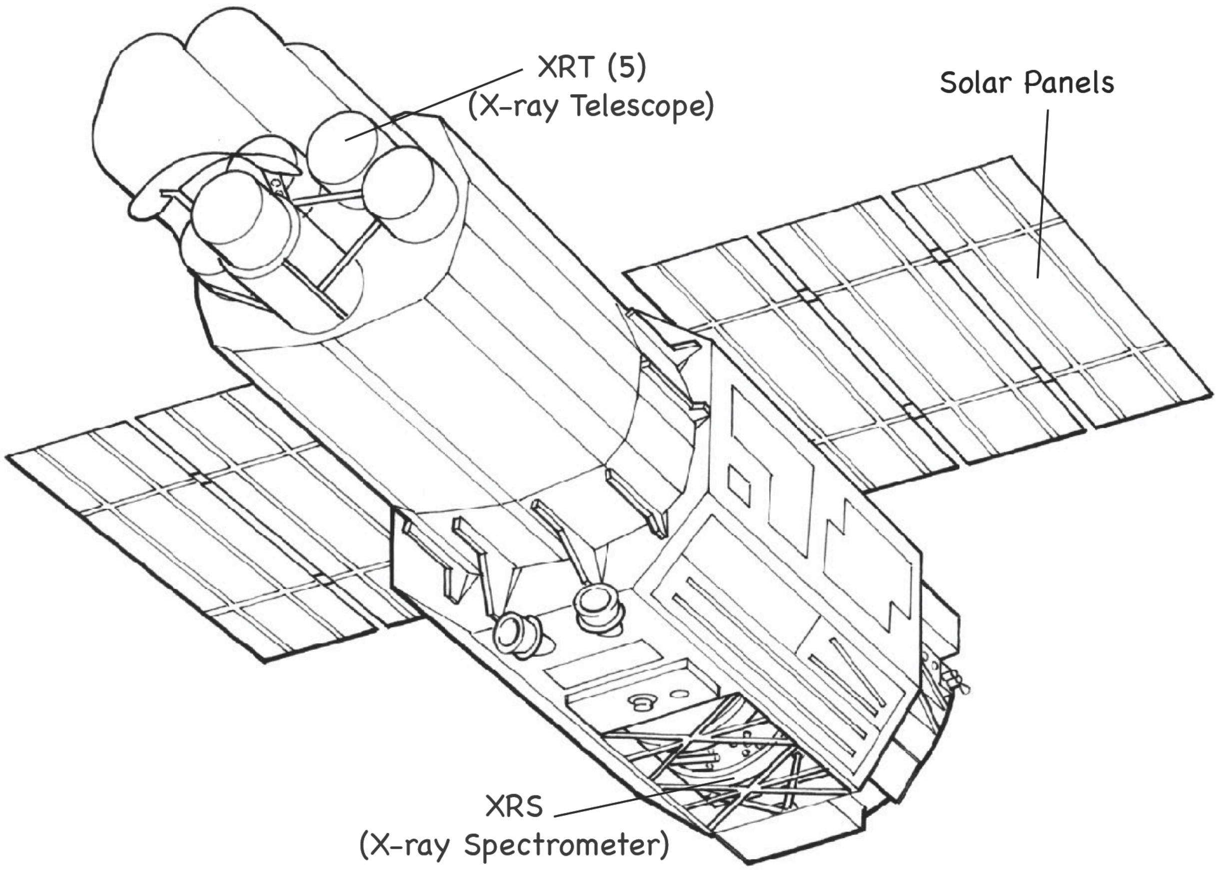
03:20
The second stage separates from the third stage and spacecraft. The cameras are on the second stage, so we see the third stage moving away from us.

03:24
The extendible nozzle of the third stage rocket is extended. It was collapsed before this point to save space. Part of the extension mechanism consists of cable-like objects which fly away from the spacecraft.

03:25
The third-stage rocket fires, directly at the second stage, thereby obliterating the cameras and their transmitters, and ending our video.

VIII. Appendix B – Suzaku Diagram

This line diagram shows the exterior of the Suzaku satellite.



IX. Appendix C – Glossary

Below are definitions of words appearing in the video. In italics is a sentence from the video where the word was used (if available). The speaker is also listed to make it easier to replay the video and find the quote. Words are listed alphabetically, not in their order of appearance. Terms relevant to the assembly of the mirrors are given on page 17-19.

absolute zero
The zero temperature on the Kelvin scale (0 Kelvin = -459.67°F = -273.15°C). It is the temperature at which all random molecular motion stops.
*The heat capacity of almost everything goes down very rapidly if you get close to **absolute zero**.* (Dr. Kevin Boyce)

accretion
Gravitational accumulation of dust and gas onto larger bodies such as stars, planets, and moons.
*And what happens is it **accretes** material. Material comes in and falls into the black hole.* (Dr. Kim Weaver)

accretion disk
A relatively flat disk of gas and dust orbiting a black hole or any massive object that is growing in mass by attracting material.
*It's going to be looking at **accretion disks** around black holes to study the gravitational effects of a black hole on the accretion disk.* (Dr. Kim Weaver)

active galactic nuclei (AGN)
A class of galaxies which spew massive amounts of energy from their centers, far more than ordinary galaxies. Many astronomers think supermassive black holes may lie at the center of these galaxies and power their explosive energy output.
*But in an **active galactic nucleus** that has a huge black hole in the center that gives off X-rays around it, around it in an accretion disk, you can use those X-rays to probe into the center of the galaxy.* (Dr. Kim Weaver)

adiabatic demagnetization refrigerator (ADR)
A specialized refrigerator that can create and maintain extremely cold temperatures below that of normal coolants like liquid helium or solid neon.
*And then inside that there's what we call an **adiabatic demagnetization refrigerator**, which uses magnetic spins inside actual atoms and aligns them and de-aligns them in such a way to get us down to 60 millikelvin.* (Dr. Kevin Boyce)

Astro-E2 (now known as **Suzaku**)
A satellite for studying X-rays emitted by stars, galaxies, and black holes. It is a joint project between Japan and the US, launched in July 2005.
*And then, the Japanese proposed a re-flight of Astro-E. We would call it **Astro-E2**.* (Narrator)

astrophysicist
A scientist who studies the part of astronomy that deals principally with the physics and chemistry of the universe.
*NASA **astrophysicist** Dr. Kim Weaver is eager to work with Astro-E2 data.* (Narrator)

black hole
An object whose gravity is so strong that not even light can escape from it.
Black holes *have extreme gravity and they create a lot of intensity and heat and energy around them, and so the regions around the black hole are going to be producing X-rays instead of optical light. So if you are going to probe a black hole, you need to be able to see X-rays.* (Dr. Kim Weaver)

bunny suit
A special garment worn in a clean room or clean tent designed to prevent dust, hair, and skin from contaminating the environment.
Keeping the clean tent environment virtually dust free requires the use of special clothing commonly referred to as ***bunny suits****.* (Narrator)

calibration
A process for standardizing the measurements produced by a measuring instrument (such as a telescope) by correcting for most of the errors caused by environmental and instrumental instabilities.

calorimeter
A device that measures the heat of chemical or physical changes.
A couple of people at Goddard came up with this idea of using a tiny piece of silicon as a ***calorimeter****, that would actually measure the heat from one single photon of an X-ray.* (Dr. Kevin Boyce)

Chandra X-ray Observatory
A NASA space mission, launched in July 1999, and named after Nobel prize winner Subrahmanyan Chandrasekhar. Chandra is designed to observe X-rays from high-energy regions of the universe.
Seven long years, that culminated in the year 2000, when Astro-E would join two other X-ray observatories in orbit; NASA's ***Chandra X-ray Observatory*** *and Europe's X-Ray Multi-Mirror Mission.* (Narrator)

clean room or **clean tent**
A special environment with a low level of environmental pollutants such as dust, microbes, vapors, and other contaminants. The air entering a clean room or clean tent is filtered and constantly recirculated to remove pollutants. This cleanliness is essential when working with equipment that is sensitive to environmental contamination.
So we had to keep everything scrupulously clean, which means doing everything that has to do with inside of the detector assembly in a ***clean room****.* (Dr. Kevin Boyce)

cluster of galaxies
A system of galaxies containing a few dozen to a few thousand member galaxies which are all gravitationally bound by the presence of hot gas, dark matter, and each other.
And also, Astro-E2 will look at clusters - the hot X-ray gas at the center of the clusters - to understand the temperature of the cluster, the mass of the cluster, and that way you can sort of probe the universe by looking at ***clusters of galaxies****.* (Dr. Kim Weaver)

Corona (pl. coronae)
The uppermost level of a star's atmosphere, which is usually heated to millions of degrees.
It's going to be looking at the ***coronae*** *of stars.* (Dr. Kim Weaver)

cryogenics
The study of the application of low temperatures and its effects.
To detect the miniscule amount of heat given off by a single X-ray, engineers must employ ***cryogenics****, the science of the super-cold.* (Narrator)

Dewar
A container (akin to a thermos bottle) designed to provide good thermal insulation (keeping cold material cold or hot material hot). In astronomy, these are often used in cryogenics to hold liquid nitrogen (at 77K) but can also be used for solid neon (17K) or liquid helium (1.3K). Some astronomical detectors work better at cold temperatures.
The XRS detectors are placed inside a Dewar. A ***Dewar*** *is like a thermos bottle. If you have a real glass thermos bottle to put your coffee in, you have a Dewar. It's two walls and in between the walls is a vacuum so the heat can't get through from one side to the other by convection. (Dr. Kevin Boyce)*

disk
A flattened, circular region of gas, dust, and/or stars. It may refer to material surrounding a newly formed star, material accreting onto a black hole or neutron star, or the large region of a spiral galaxy containing the spiral arms.

dry ice
Solid (frozen) carbon dioxide. Instead of melting like water ice, dry ice sublimates, or goes directly from solid to carbon dioxide gas at -78.5°C (-109.3°F).
Dry ice *is frozen carbon dioxide. It's a lot colder than regular ice, but the key thing is it doesn't melt; it just turns back into* CO_2 *gas.* (Dr. Kevin Boyce)

dust
Not the dust one finds around the house (which is typically fine bits of fabric, dirt, and dead skin cells), but rather, irregularly shaped grains of carbon and/or silicates measuring a fraction of a micron across, which are found between the stars. Dust is most evident by its absorption of light coming from behind it, which causes large dark patches in regions of our Milky Way galaxy and dark bands across other galaxies.
A galaxy is filled with all sorts of stars and gas and ***dust****. And that gas and dust blocks our view to the center of the galaxy.* (Dr. Kim Weaver)

electromagnetic radiation
Also referred to as light regardless of wavelength. A propagating wave in space made up of oscillating electric and magnetic components.
X-rays are light. It's ***electromagnetic radiation*** *just like optical light, but it's at a different wavelength.* (Dr. Kim Weaver)

electromagnetic spectrum
The full range of frequencies, from radio waves to gamma rays, that characterizes light.

element
A substance which cannot be decomposed into another substance by chemical means. The most abundant elements in the universe are hydrogen and helium. Despite comprising only a very small fraction the universe, the remaining heavy elements can greatly influence astronomical phenomena. About 2% of the Milky Way's disk is comprised of heavy elements.
*It'll be looking at supernova remnants to understand the chemical **elements** created when a star explodes.* (Dr. Kim Weaver)

frequency
A property of a wave that describes how many wave patterns or cycles pass by in a period of time. Frequency is often measured in Hertz (Hz), where a wave with a frequency of 1 Hz will pass by at 1 cycle per second.

galaxy
A component of our universe made up of gas and a large number of stars (usually more than a million) held together by gravity.
*A **galaxy** is filled with all sorts of stars and gas and dust.* (Dr. Kim Weaver)

gamma ray
The highest energy, shortest wavelength electromagnetic radiation. Usually, they are thought of as any photons having energies greater than about 100 keV. (It's "gamma-ray" when used as an adjective.)

gravity
The mutual physical force attracting two bodies.
*The black hole has a huge amount of **gravity**, so it brings material toward it.* (Dr. Kim Weaver)

Goddard Space Flight Center (GSFC)
One of the centers operated by NASA, located in Greenbelt, MD.
*Work on Astro-E2 is happening at the NASA **Goddard Space Flight Center** and in Japan simultaneously.* (Narrator)

heat capacity
The ability of matter to store heat. The heat capacity of a certain amount of matter is the quantity of heat (measured in joules) required to raise its temperature by one kelvin. The SI unit for heat capacity is J/K (joule per kelvin).
The heat capacity of almost everything goes down very rapidly as you get close to absolute zero. (Dr. Kevin Boyce)

Institute of Space and Astronautical Science (ISAS)
A space science research institute in Japan, part of the Japan Aerospace Exploration Agency (JAXA).
*In 1993, scientists and engineers from NASA's Goddard Space Flight Center and **ISAS** in Japan joined forces.* (Narrator)

jets
In this context, beams of particles and energy, usually coming from objects like active galactic nuclei. In a particular object, jets generally come in pairs aimed in opposite directions.
*The black hole can not only eat material, but it can cause material to be pulled in a spiral upward and be shot away from it, into **jets** on opposing sides.* (Dr. Kim Weaver)

kelvin (after Lord Kelvin, 1824 - 1907)
The fundamental SI unit of temperature defined as 1/273.16 of the temperature of the triple point of water. More practically speaking, the kelvin temperature scale measures an object's temperature above absolute zero, the theoretical coldest possible temperature. On the kelvin scale the freezing point of water is 273 (= 0°C = 32°F). The kelvin temperature scale is often used in sciences such as astronomy.
*There's an outer layer of solid neon that's 17 **kelvins**. That's pretty cold for you and me but it's still blazingly hot for our detectors.* (Dr. Kevin Boyce)

light
The common term for electromagnetic radiation, usually referring to that portion visible to the human eye. However, other bands of the electromagnetic spectrum are also often referred to as different forms of light.
*So, if you put **light** through a prism, you get a spectrum of colors – same thing is true of X-rays.* (Dr. Kevin Boyce)

metrology
The science of making precise measurements of positions, sizes, and orientations.
*It goes into the **metrology** lab where the foil is inspected.* (Mr. Curtis Odell)

microcalorimeter
A detector designed to measure very small temperature increases.
*At the very heart of the XRS instrument is the **microcalorimeter** array.* (Dr. Caroline Kilbourne)

optical light or **visible light**
Electromagnetic radiation at wavelengths which the human eye can see. We perceive this radiation as colors ranging from red (longer wavelengths; ~700 nanometers) to violet (shorter wavelengths; ~400 nanometers).
*The galaxy is filled with all sorts of stars and gas and dust. And that gas and dust blocks our view to the center of the galaxy. So if we look at it in **optical light**, we can't see the center of the galaxy.* (Dr. Kim Weaver)

photon
The smallest (quantum) unit of light/electromagnetic energy. Photons are generally regarded as particles with zero mass and no electric charge.
*Each X-ray **photon** has much, much more energy than an individual optical photon.*
(Dr. Kim Weaver)

spectrometer
An instrument that separates light signals into different frequencies, producing a spectrum.
*The X-ray **spectrometer** is so sensitive that it can detect extremely subtle differences between individual X-ray photons.* (Narrator)

spectroscopy
The study of spectral lines from different atoms and molecules. Spectroscopy is an important part of studying the chemistry that goes on in stars and in interstellar clouds.
Spectroscopy *is the ability of telling what are the different phenomena that occur.* (Dr. Ilana Harrus)

spectrum
The distribution of light over a range of frequencies, often shown in a plot, chart, or image.
It looks at the ***spectrum*** *of photons that come from a given source.* (Dr. Kevin Boyce)

sublimation
A phase transition between the solid and the gaseous phases of matter, with no intermediate liquid stage.

supernova
The death explosion of massive star or of a white dwarf, resulting in a sharp increase in brightness followed by a gradual fading. At peak light output, supernova explosions can outshine a galaxy. The outer layers (or in the case of the white dwarf, the entire star) are blasted out in a radioactive cloud. This expanding cloud, visible long after the initial explosion fades from view, forms a supernova remnant (SNR).
It's going to be looking at ***supernova*** *remnants to understand the chemical elements created when a star explodes.* (Dr. Kim Weaver)

Voyager space probes
Twin space probes launched by NASA in 1977 to explore the large outer planets of the solar system and the solar atmosphere, now headed out of the solar system into interstellar space.
The first time I realized I would kind of like to do this was when I read a story in Scientific American many years ago, maybe in high school, about the ***Voyager space probes*** *and all the problems they had.* (Dr. Kevin Boyce)

wavelength
The distance between adjacent peaks in a series of periodic waves.

X-ray Multi-Mirror Mission (XMM-Newton)
An X-ray spectroscopy mission, launched in December 1999 by the European Space Agency, designed to observe high energy X-rays emitted from astronomical objects such as pulsars, black holes, and active galaxies.

X-ray
Electromagnetic radiation of very short wavelength and very high-energy; X-rays have shorter wavelengths than ultraviolet light but longer wavelengths than gamma rays.
X-rays *are light. It's electromagnetic radiation, just like optical light, but it's at a different wavelength. X-rays have a shorter wavelength and they carry much more energy.* (Dr. Kim Weaver)

X-ray astronomy
The field of astronomy that studies celestial objects by the X-rays they emit.
*In **X-ray astronomy**, the objects out there - the stars, the supernovae, the galaxies, the black holes - are producing the X-rays. We send up a telescope that just detects the X-rays.*
(Dr. Kim Weaver)

XRS (X-Ray Spectrometer)
The name of Astro-E2's primary instrument, which records spectra at X-ray energies.
*Astro-E2's primary instrument, the X-Ray Spectrometer, or **XRS,** is being built here, at NASA's Goddard Space Flight Center.* (Narrator)

XRT (X-Ray Telescope)
An instrument designed to gather X-rays and bring it to a focus on a detector, where the X-rays can be analyzed.
*We use an **X-Ray Telescope**, which depends on a grazing incidence reflection, in which the reflectors are nearly edge on to the X-ray source.* (Mr. Curtis Odell)

X. Frequently Asked Questions

We tried to anticipate some questions that you might have by getting a group of educators together and asking them where they would want to know more. What follows are some of their questions with short answers. Some answers include places to go to find more in depth information.

General Information about Suzaku

- **How big is Suzaku and what will its orbit be like?**
  The spacecraft is approximately 6.5 x 1.85 m when functioning in orbit. It has a mass of 1.7 metric tons. Suzaku is in an almost circular orbit around Earth, with a perigee of 566 km, an apogee of 569 km, and 32 degrees inclination. For pictures of Suzaku and its instruments, see:
  http://suzaku-epo.gsfc.nasa.gov/docs/astroe_lc/gallery/images.html
  http://www.nasa.gov/pdf/117851main_astro-e2_infosheet.pdf

- **What are Suzaku's capabilities?**
  Suzaku has a data collection lifespan of about 5 years. The XRS instrument was expected to collect data for 2 to 3 years, limited by the amount of liquid helium. Suzaku can detect X-rays with energies ranging from 10 to 700 keV using two other instruments, the X-ray Imaging Spectrometer, and the Hard X-ray Detector. For more details, go to: http://suzaku-epo.gsfc.nasa.gov/docs/astroe_lc/science/instruments/instruments.html.

- **What are the differences in what we can learn from Hubble vs. Suzaku?**
  The major difference is the type of light collected and studied by each. The Hubble Space Telescope (HST) collects data in the visible and near visible parts of the spectrum, while Suzaku collects data in X-rays. X-ray energies are thousands of times more energetic than optical and come from processes that occur mainly in regions of high temperature, strong gravity, or strong magnetic fields.

  A good analogy might be to compare just looking at the human body vs. using an X-ray machine. A visual look gives us good, detailed information about certain areas and processes in the body, and an X-ray image provides complimentary information. Visual inspection tells us little about a broken bone, whereas an X-ray will not help diagnose a strep throat. Together they provide data to give us a clearer picture.

  Using different wavelengths of light to provide a more complete view of an object or process in space is referred to as *multiwavelength astronomy*. For further study, try: http://imagine.gsfc.nasa.gov/docs/science/know_l1/multiwavelength.html.

- **Why does Suzaku need to be in space?**
  The earth's atmosphere filters the wavelengths of light that reach the surface. This allows some wavelengths of light to reach the surface, while others are prevented from doing so, much as a pair of sunglasses only allows some wavelengths of light to reach your eyes. Radio waves and visible light reach the surface, but most X-rays do not. This makes it impossible to detect the X-rays from observatories on the ground. So we must use space-based observatories to detect and study these X-rays.

Culture and collaboration

- **How did NASA come to build the microcalorimeter?**
  Scientists at NASA's Goddard Space Flight Center in Greenbelt, MD invented the concept of using the microcalorimeter as an X-ray spectrometer in the early 1980s. Although the theory is simple and elegant, it took years of technological developments to translate the theory into practice. The instrument is complex enough that you have to design and build a detector, test it, revise the design many times, each time tweaking a parameter here and another parameter there to improve the performance. But a working detector was achieved in the mid 1980's.

- **How did Japan and the US come together for this mission?**
  The collaboration between the NASA Goddard X-ray Group and the Japanese dates back to the mid 1980s. The X-ray group was developing the lightweight X-ray mirrors, and the Japanese were looking for lightweight optics for their planned Astro-D satellite (later named ASCA), scheduled to be launched in 1993. So the Goddard X-ray group provided the mirrors for that satellite, which operated successfully for 7 years. Later, when planning Astro-E, the Japanese again asked NASA to supply another set of these mirrors.

  After the microcalorimeter was developed, it was selected to be flown on NASA's planned Advanced X-ray Astrophysics Facility (AXAF). However, in 1992, a new plan for AXAF split it into two satellites: AXAF-I would primarily perform high resolution X-ray imaging, and AXAF-S would perform high-resolution spectroscopy using the microcalorimeter. (AXAF-I was launched in 1999 and was renamed the Chandra X-ray Observatory.) In 1993, the Japanese space agency ISAS was looking for a new instrument to put on their next X-ray observatory, Astro-E. NASA and ISAS agreed that, rather than flying AXAF-S, the microcalorimeter would become the prime instrument on Astro-E. The Goddard team successfully built the microcalorimeter for Astro-E, but as the video describes, Astro-E suffered a launch failure,

- **What does the name "Suzaku" mean?**
  "Suzaku" means "vermilion bird of the south," originally from Chinese mythology. It is an appropriate name for this mission for several reasons. In mythology, Suzaku is a red sparrow-like bird, which guards us from evils and gives us good fortune. This also fits in with the tradition of Japanese X-ray astronomy satellites, which are often named after birds.

  Japanese X-ray astronomy started with Hakucho (swan, or constellation Cygnus, whose Chinese characters mean "white bird"), which was a recovery mission for the failed CORSA-A. Just as Japanese X-ray astronomy built on the success of Hakucho, the Japanese (and the international) X-ray astronomy community hope to start a new era with the new satellite named Suzaku.

  In Japanese history, emperors after the Asuka era in the 7th century built capital cities after the Chinese model. In Chinese legends, these cities were guarded by four deities. The white tiger is the guardian of the west, the black turtle for the north, blue dragon for the east, and the vermilion bird for the south. Suzaku, the vermilion bird, was a leading deity of the time following the Asuka era. In Chinese astrology, 28 constellations of the zodiac are governed by the four deities mentioned above. The vermilion bird, Suzaku, governs the southern part. The Virgo cluster of galaxies, one of the most important targets of the new mission, is located in the part of sky governed by Suzaku.

朱雀

Suzaku, written in Japanese.

- **What are the names of some of the other Japanese X-ray Observatories**
  The Japanese assign their satellites a pre-launch project name (e.g. Astro-E) and rename them formally once they are successfully in orbit. Their satellites are never named after a person, but usually after an appropriate symbol from Japanese mythology, history or star lore. The previous satellites in the Astro series were:
  Astro-A became Hinotori (Japanese for Phoenix);
  Astro-B became Tenma (Japanese for Pegasus);
  Astro-C became Ginga (Japanese for galaxy);
  Astro-D became ASCA, short for the Advanced Satellite for Cosmology and Astrophysics (although it is similar to the ancient Japanese word Asuka, meaning "flying bird").

Cryogenics and thermodynamics (What's hot and what's not)

- **How cold is 0.060 K? How can we visualize it?**
  Many measurements and numbers are difficult to visualize and understand. Room temperature is around 300 K, and the temperature of deep space is an unimaginable 3 K, so 0.060 K is "off the charts".

  One way scientists deal with such numbers is to use logarithmic (powers of ten) scales and "orders of magnitude." One order of magnitude represents a difference of ten times. For example: 10 is one order of magnitude lower than 100, and two orders of magnitude lower than 1000.

  The difference between room temperature (300 K, or $3x10^2$) and 0.060 K ($6x10^{-2}$) is four orders of magnitude, because the difference between the exponents is four - and only the exponents of 10 are important here. The Richter scale for earthquakes is logarithmic, as is pH in chemistry.

  You can visualize 0.060K with a stack of books. If each book represents 1 K, then a stack of 300 books would represent room. If each book is 500 pages long, then 0.060 K would be the thickness of 30 pages! So there you have it…30 pages vs. 300 books!

- **With all that effort, why not a longer mission or why not figure out a way to recharge the cooling system to extend the mission?**
  The simple answer is cost. Space travel is expensive to the point that recharging the Dewar is not practical. So the cost/benefit ratio is too high. Designing a repair mission requires developing complex technologies that span engineering disciplines from

aerospace to robotics. And those technologies would only apply to the one mission, because each spacecraft/instrument/launch vehicle/orbit/etc. combination is different.

Could the space shuttle help us out? In this case, no. The orbit of Suzaku is much higher than the orbit obtainable by the shuttle.

- **Why are helium and neon used?**
  Helium and neon are both noble gases (found in the rightmost column of the periodic table). They do not combine with other elements. They also have low molecular weights and liquefy and solidify at very low temperatures. These physical properties make them ideal insulators in the Dewar to help in cooling the microcalorimeter.

Science

- **What types of objects does Suzaku study?**
  Suzaku studies the regions of strong gravity around *black holes*. It also probes *galaxy clusters,* which are regions where large numbers galaxies are found together due to their gravity. *Supernovae remnants* are regions of expanding gases and dust from a former star that gravitationally collapsed, creating heavy elements in the process. *Stellar coronae* are areas that are intensely hot (millions of K). For more information on what is being studied by Suzaku, please see:
  http://suzaku-epo.gsfc.nasa.gov/docs/astroe_lc/science/science.html.

- **Why are X-rays emitted from celestial objects?**
  X-rays arise from two general types of physical processes. The first is when electrons are accelerated. X-ray processes mostly occur at very high temperatures. Free electrons moving around in a plasma (very hot gas where electrons are unattached to nuclei) come near an atomic nucleus or a strong magnetic field, and become accelerated. The second process occurs in atoms when an electron may drop one or more energy levels to fill in a lower energy level, thus releasing a great deal of energy. X-rays are emitted from many elements when electrons fall to the ground or first excited state. An excellent resource to find out more can be found at:
  http://imagine.gsfc.nasa.gov/docs/science/how_l2/xray_generation_intro.html

- **Will Suzaku study planetary systems?**
  Suzaku will not study planetary systems around other stars. Planets are very weak X-ray emitters, and present technology does not allow their X-ray signals to be separated from that of the parent star.

Significance and meaning

- **What is the impact of the science of Suzaku on us?**
  Scientists want to study spectra of objects in space, and Suzaku will provide this data to a greater resolution than ever before. This will allow scientists to better understand the chemical makeup and structure of complex, intriguing objects, such as galaxy clusters, supernovae, and black holes. More information is available at:
  http://suzaku-epo.gsfc.nasa.gov/docs/astroe_lc/science/science.html.
  This site also includes announcements of new discoveries made by Suzaku.

- **Why is this important to me? What is its purpose?**
  There are two answers to this:

  First, it is in the best interest of the US to maintain its role as a leader in space exploration. From this, many materials and processes that improve daily life have been developed. These developments frequently help support a robust economy and our national security, which contributes to maintaining or improving our standard of living. For more information about technology “spinoffs” from space exploration, visit: http://www.sti.nasa.gov/tto/index.html

  Also, it is human nature to explore. Science is a natural outgrowth of this desire. Throughout human history, civilizations have always “pushed the envelope” to explore new frontiers and gather information about distant places. Space exploration continues this tradition that makes us richer as people, as a nation, and as a species.

Name ____________________________ Date ____________ Class Period ______

Worksheet for Chapter 1 – Astro-E2: History, People, and Science

Directions: After watching this video chapter, write your answers to the following questions.

1. What was Astro-E?

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2. What happened to Astro-E?

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3. How did the scientists respond when they heard about the failure of Astro-E?

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4. What will Astro-E2 look for?

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5. How do black holes produce X-rays?

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Name ____________________________Date ____________ Class Period ______

Worksheet for Chapter 2 – X-ray Spectroscopy and the Microcalorimeter

Directions: After watching this video chapter, write your answers to the following questions.

1. What does XRS stand for? What does it do?

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2. What is Chandra? How does Chandra relate to Suzaku (Astro-E2)?

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3. How do the US and Japanese teams look at their working relationship?

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4. What did you see in the footage from Japan that looks familiar? What looks different?

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5. In your own words, describe Dr. Harrus's stadium analogy. What do the balls represent? What do the games represent? What will Suzaku do?

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Name ____________________________ Date ____________ Class Period ______

Worksheet for Chapter 3 – Building the X-ray Spectrometer and the X-ray Telescopes

Directions: After watching this video chapter, write your answers to the following questions.

1. Why does the microcalorimeter have to be so cold?

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2. How is the microcalorimeter kept so cold?

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3. How does a clean tent work?

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4. What do you think it would be like to work in a clean tent?

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5. What material is put on to the surface of the metal foils in the telescopes?

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Name ____________________________ Date ____________ Class Period ______

Worksheet for Chapter 4 – Overcoming Challenges and Moving On

Directions: After watching this video chapter, write your answers to the following questions.

1. Why does the telescope team keep testing at every stage?

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2. How would you approach a problem like the leak in the XRS Dewar?

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3. How did the team keep track of their schedule?

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4. Why was dry ice, rather than water ice, used for packing the telescope?

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5. Imagine you are on the Suzaku team. How would you feel when the telescope was all packed up to go to Japan?

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