Dying Stars and the Birth of Elements

Shortly after the Big Bang, the only elements in the universe were hydrogen (~74%) and helium (~23%). Looking at the universe today, we still see mostly hydrogen and helium. That's not the whole story, though. If it were, we wouldn't be standing here today.

If you think about the elements needed for us to be standing here, you might first think about oxygen (to breathe, and also to combine with hydrogen to make water), or carbon. Before life can even form, though, the elements necessary for planet formation must be created. Where did all of these elements come from?

Today, we know through observations and model-fitting that fusion occurs in stars. Could that be the source of the new elements? Fusion takes two lighter elements and builds a heavier element from that. Unfortunately, you can only get as large as iron (Fe). Heavier elements than that have to be made another way. Another problem is getting the products of fusion out of the star's core. If the elements are inside of a dead star, they aren't much use!

So we have two questions to answer: *how do we make the elements we need?* and *how do we get those elements out into space?* One idea is that the elements are created in stars and then put into space when that star explodes violently. Stars like our Sun will never explode, so we need to see if massive stars (that will explode in a supernova) can make enough elements to make the dust and planets that we observe in the galaxy.

To do that, we are going to use a technique called **X-ray spectroscopy**. By looking at the spectrum of a supernova remnant, we can see how much of each element is in the exploded star. We will be looking at the **Cas A** supernova.

Procedure

Step 1: Setting up the Telescope

1. Click on the CLEA folder on the desktop

2. Start the program

3. Log in, using initials for each group member and your group number

4. Go to **File → Run Exercise...**

5. If a window pops up asking you for your time zone, enter **-6** for CST

When you first run the program, a control panel opens which enables you to virtually point and operate a simulation of the orbiting XMM-Newton X-ray telescope. To start the observation, first point the telescope at the supernova remnant.

6. Go to **Slew → Hotlists → Objects**

7. An "Observation List" window will pop up with a set of coordinates. **Double-click** on them. The telescope will move to the position of the supernova remnant.

8. Under the **View** section (on the right), change the field of view to **Chart**. The crosshairs will show you where you are pointed (the center of the supernova remnant).

9. Use the direction buttons on the left (**N, S, E, W**) to move the crosshairs into the box labeled "Field 1". To go faster or slower, click on **Slew Rate**.

10. Once the telescope is in the field, change your **View** to **Field**. This will provide a "close-up" view of the field.

Your targets are the four bright clumps of gas, or "knots," near the center of the screen, labeled "1" through "4". **Each group will do one knot.**

11. Slew to the knot assigned to your group and center the knot in the window. **Make sure your target is centered in the crosshair.** If it isn't, then it will take longer to observe because not all the light from the target is getting into the telescope.

Step 2: Taking an Observation

Now that the telescope is pointed on your knot, you can use the spectrometer to take data. Because we are observing X-rays, the spectrometer is a little more complicated than a simple prism, but the idea is the same: spreading the light out so we can look at the intensity of different wavelengths.

1. Click on the **Spectrometer** button to open the spectrometer window.

2. Find the "signal-to-noise ratio" on the screen. You will try to get a signal-to-noise **between 15 and 20**. (Usually you want as big a number as possible, but the software breaks if you go higher than 20. Think of it as you weren't given more telescope time and have to make due with less than that.)

3. Click on the **Go** button. The spectrum can be seen building up, photon by photon, as the exposure increases. To stop the exposure, simply click the **Stop** button. Exposures can be continued by simply clicking **Go** again.

4. Once your spectrum looks good, save it by going to **File → Save**. YOU MUST DO THIS or you will have to take a new one.

5. *Once you have saved*, close the spectrometer window.

Step 3: Analyzing Data

Now that you have a spectrum, you can compare it to a mathematical model that includes how each element produces X-rays. You can change the amounts of several elements and see how the model spectrum changes. You can also change the temperature and a few other parameters. As you adjust the model *parameters*, the model *spectrum* will change. The goal is to get the model spectrum to match the observed one. The model of the knot you have created will then closely match the real characteristics of the observed knot. You will have determined the physical nature of the gas in the supernova remnant!

From the **main telescope control window**

1. Select **Tools → Spectrum Analysis**

2. **Go to File → Load Spectrum…** Your spectrum will appear in the middle plotting area.

3. Load the model by going to **Tools → Comparison Spectrum.** This will appear in the top plotting area.

4. Look at the bottom plotting area. This is the *difference* between the Comparison Spectrum (model) and the spectrum you took.

5. Look at the controls labeled **X-ray Comparison Spectrum Model Parameters**. You can use the sliders to change the chemical composition, temperature, and density of the model *(note: some of these are already fixed at their correct values; they appear dimmer in the display.)* **Before you play with them, read the tips below.**

6. Once you think you have a good spectrum, check with your laboratory instructor. If it is good, write your numbers in **Table 1** and on the board, and answer the questions in the answer packet.

You have two goals in making a good model fit to your spectrum:

Goal 1: Try to get the difference spectrum to be as flat as possible.

Goal 2: Try to get the "Quality of Fit" as low as possible. It must be less than 1 to qualify as a "good" fit – but you can get lower than that!

The parameters are:

Temperature (kT): this is the temperature of the gas. You can think of a gas at a temperature of 1 keV being equivalent to about 10 million degrees Celsius – almost as hot as the core of the Sun!

Absorption (nH): This represents the amount of cool, Galactic hydrogen gas between you and the X-ray emitting gas. The more gas there is, the more X-rays it absorbs out of the spectrum.

Iron (Fe): This is the abundance of the element iron in the gas, relative to the abundance of iron in the Sun. An iron abundance of 1.0 in a sample of supernova gas means it has the same ratio of iron in it that the Sun does. 2.0 means twice as much, and so on.

Sulfur, Silicon, Calcium, Magnesium: Same as iron, but abundances for those elements.

TIP 1: *Every time you adjust a parameter, go back and adjust all the parameters you already adjusted. This way you will converge more rapidly on a good solution. If you simply move down the list of parameters once, you'll never get a good fit.*

As you adjust a parameter, note what is changing. You may find that some things change in similar ways when two different parameters are adjusted.

TIP 2: *You may appear to be getting close to a solution, and then find that you are suddenly not improving. This is normal. Try moving one of the sliders quite a bit, to break out of that impasse. Try again using very different parameter values to start wit, to make sure you don't get locked into those incorrect values again.*

Be patient. This takes some getting used to. It may take a few minutes when you first try it.

TIP 3: *Watch the "Quality of Fit" number as you move a slider. When it drops to a minimum value, move to another parameter. When it's again at a minimum, go back to the first parameter and adjust it again. This method will let you converge on a solution more rapidly.*

Once the "Quality of Fit" value drops below about 1 (the specific value is different for every observation depending on the knot you observe and the signal-to-noise ratio you achieved), you are getting close. Note that the display for it turns green, letting you know your fit is getting good. Keep adjusting the sliders to get this value as low as possible.