ISYA VO Exercise

Estimating the Age of Supernova Remnants

Background:

There is controversial evidence that the British astronomer John Flamsteed observed and recorded the Cas A supernova event in his journal on the evening of August 16th, 1680. He observed a star that was near the position of Cas A, not observed by anyone else, and was never seen again - it could have been the explosion that produced Cas A.

The Cas A remnant is ~11,100 light years away, and if John Flamsteed did observe the catastrophic collapse of the massive star ~330 years ago, the supernova event occurred approximately 11,430 years ago. There are some scientific methods of analyzing supernova remnants to try and determine their age; this exercise utilizes ds9 image analysis software and Chandra X-ray observational data.

Purpose: To use the observed size of the Cassiopeia A supernova remnant (SNR) from its X-ray image and an estimated rate of expansion to calculate its approximate age.

Procedure:

How Big is Cas A?

1. Open SAOImage ds9. Go to **Analysis>Virtual Observatory**. Choose any of the servers from the menu.
2. Choose **Obs ID 114, ACIS OBSERVATION OF CAS A** from the list. The Cas A image will load into your ds9 window.
3. To better view the edges of **Cas A**, choose **Scale>Square Root** and **Color>Invert Colormap**.
4. Left click on the black dot (neutron star) in the center. Holding the left click button down, drag a circular region around the edges of the supernova remnant. Exclude the jet in the upper left from the region - the dynamics of this jet formation are different that those of the overall expansion of the SNR.
5. Left click in the center of the green region to select it. Adjust the radius of the region by positioning the pointer over one of the square boxes in the corner and left clicking and dragging the pointer. Adjust the position of the region by putting the pointer in the middle, left clicking and dragging.
6. Select **Region>Get Info...** Record the radius of your region (and of Cas A) in pixels and also the x- and y-coordinates of the center of the region - you will need the radius in #9 below. Make sure it says "physical" next to each of these.
7. To find the radius of Cas A in meters, use the small angle approximation. Imagine the lines of sight from Cas A to Earth. These lines form an angle, Θ.

On a Chandra image, 1 pixel corresponds to 0.5 arc seconds of angle. Find the angular size of the radius of Cas A in arc seconds and convert to radians.

8. The lines of sight are the radii of an imaginary circle with Earth at the center and Cas A on the circumference. The radius of this circle is the distance to Cas A. For very small angles, the radius of Cas A is approximately equal to the arc length transcribed by these lines of sight. Therefore, the small angle formula is as follows, where Θ is in radians:

   Θ= **(radius of Cas A) / (distance to Cas A)**

   Using the small angle formula and a distance to Cas A of ~11,100 light years, find the radius of Cas A in meters.

   What is the rate of expansion of Cas A?

   The average amount of energy released in a supernova explosion is ~10^{44} Joules, and approximately one quarter of the energy drives the expansion of the remnant. Although the initial explosion ejects the outer layers of the star, most of the gas in the remnant is not from the star itself. As the ejected material expands outwards, it encounters and intermingles with the interstellar medium and propels it outward, building up the outer shock wave. The volume through which the remnant has expanded and the density of the interstellar medium determine the amount of material in the shell. On average this density is approximately 10^{-21} kg/m^3.

9. The Cas A SNR is basically a sphere. Determine the mass of the gas within the remnant using the radius previously calculated in #7 above.
10. Calculate the velocity of the gas (the expansion velocity of Cas A).
11. Use the expansion velocity and the radius of Cas A to estimate its age. Convert from seconds to years.
12. What is the displacement of the remnant from the center of the SNR?
13. In the center of the remnant, a dot marks the location of the remaining core of the collapsed star. Find the physical x- and y-coordinates of the core by moving the pointer over the core remnant (this will appear as a dark gray dot towards the center of the remnant with Invert Colormap). The box in the upper right corner is a close up view of the location of the pointer. With the pointer over the core remnant, record the x- and y-coordinates next to "Physical" in the table at the top left.
14. Use the coordinates of the center of the region (from #6 above) to find the displacement of the stellar core from the center.
15. Find the average velocity of the stellar core for this displacement.
16. Using this average velocity, find its kinetic energy. Evidence indicates the core is a neutron star with a typical mass of about 1.4 solar masses.

Conclusions and Analysis:

17. How does your estimated age for Cas A compare to 330 years? Does it have

the same order of magnitude?

18. What approximations and assumptions were made in this method of estimating the age of a supernova remnant? How might these affect the results?
19. Could Cas A be the supernova observed by John Flamsteed in 1680? Why or why not?