JS9 Science Olympiad Problems and Solutions

Fort Collins, 2018

Cas A

21. Cas-A is a Type II supernova remnant, which happens to be the strongest extra-solar radio wavelength source in the sky (at high frequencies). An X-ray observation from the Chandra satellite is shown in image 36 using JS9. We will set out to explore this fascinating object in depth.

    (a) First, we want to find out what the actual physical diameter (in km or parsecs) of this object is. To allow us to calculate this, we must know the object's distance and angular size in the sky. The Chandra satellite has an image resolution of 0.5" per pixel. How can you use that number to determine the angular size of Cas-A?

    (b) The distance is tricker to get, but fortunately, some interesting data about Cas-A has been collected over the years, that document the remnant's expansion. Fast moving knots of gas have been observed over decades to be moving at about 5000 km/sec. What phenomenon allows us to determine this velocity?

    (c) If, in 10 years, a knot has been observed to move 3" across our line of sight, use the information provided in part (b) to estimate the distance to Cas-A, in kilo-parsecs.

    (d) Now, using the pixel diameter shown on the JS9 image 36, estimate how big the remnant is at this time in its evolution. Display your answer in parsecs.

    (e) Suppose this same knot is now 100" from the center of the remnant. Approximately how many years ago did the supernova explode? What approximation (if any) did you use to answer this?

22. Let us now turn to an analysis of the X-ray energy spectrum emitted from this object. Image 37 shows the total energy output from the encircled region, out to an energy of 9000 eV (9 keV).

    (a) This is the same observation as we explored in the previous question. Why does this image show such different colors?

    (b) What do the various peaks in this plot tell us?

(c) Why does the energy emitted almost disappear past 7 keV?

(d) Now look at the two energy spectra shown in images 38 and 39. These correspond to X-ray radiation associated with the small encircled regions displayed. What do you notice immediately in these spectra?

(e) What does this tell you about the supernova explosion that produced this remnant?

Solutions

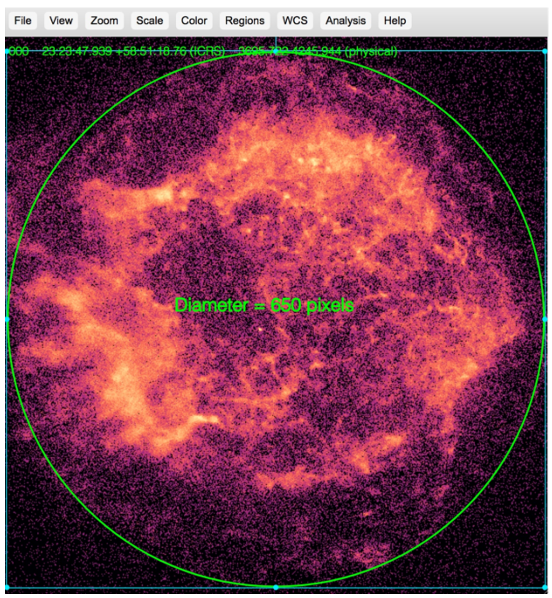

Image 36

Question 21.

(a) Multiply the number of pixels subtended by the object by resolution (0.5” per pixel) to get angular diameter.

(b) The Doppler Effect

(c) Moving at 5000 km/s, in 10 years the knot will traverse (approximately):
s = 5000 x 10 x 3.16 x 10^7 km = 1.6 x 10^{12} km.

So, **Distance to Cas-A** = s * (206,265 arc-seconds/1 radian)/3 arc-seconds
= 1.6 x 10^{12} km * 206,265 /3 = **1.1 x 10^{17} km = 3.5 kpc**

(d) **Physical Size of the Remnant** = θ(arc-seconds)x (1 radian/206,265 arc-seconds) x distance to the remnant (pc)
= (325 arc-seconds)(1 radian/206,265 radians)*(1.1 x 10^{17} km)*(1 Parsec/3.09 x 10^{13} km)
= 5.6 pc

=5.6 pc * 3.2156 light years/Parsec **= 18 light years across**

(e) **Assuming a constant velocity of expansion**, if the remnant knot is expanding at the rate of 3" /10 years, and it is 100" from the origin of expansion (the center of the remnant), the supernova was first visible from the Earth approximately 100"/(3"/10 years) or about 333 years ago. (Around 1685 CE).

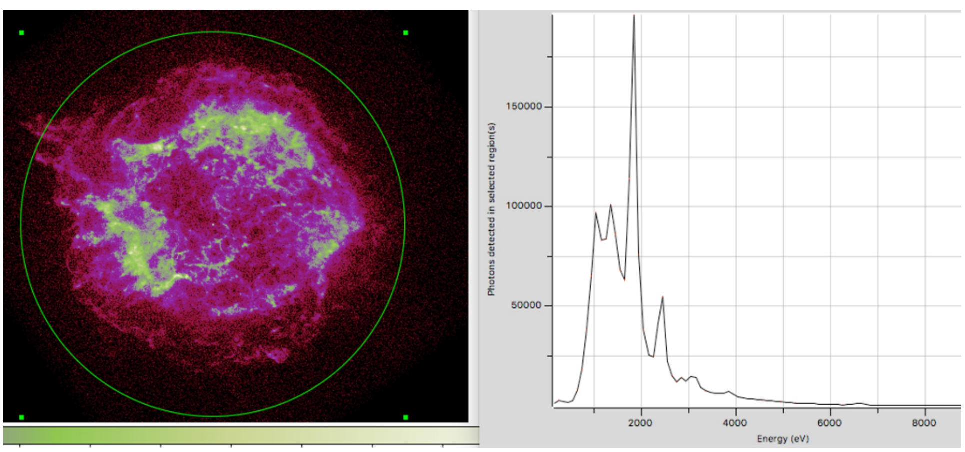

Image 37

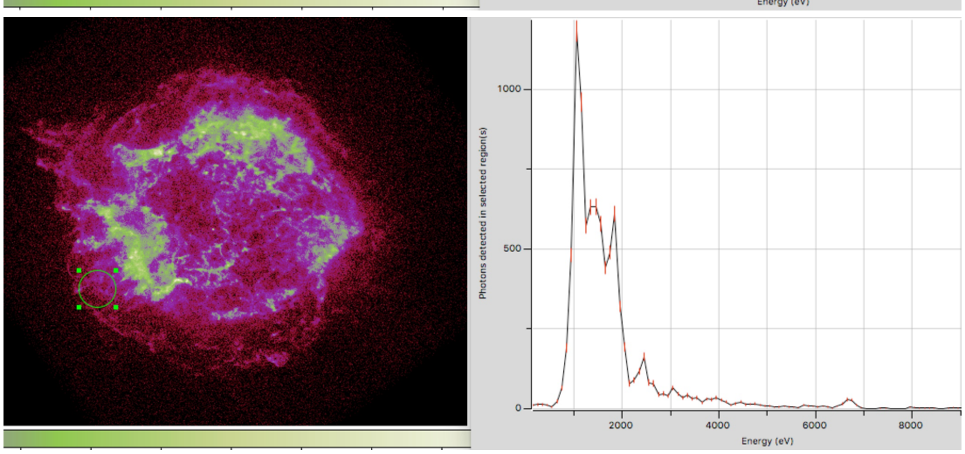

Image 38

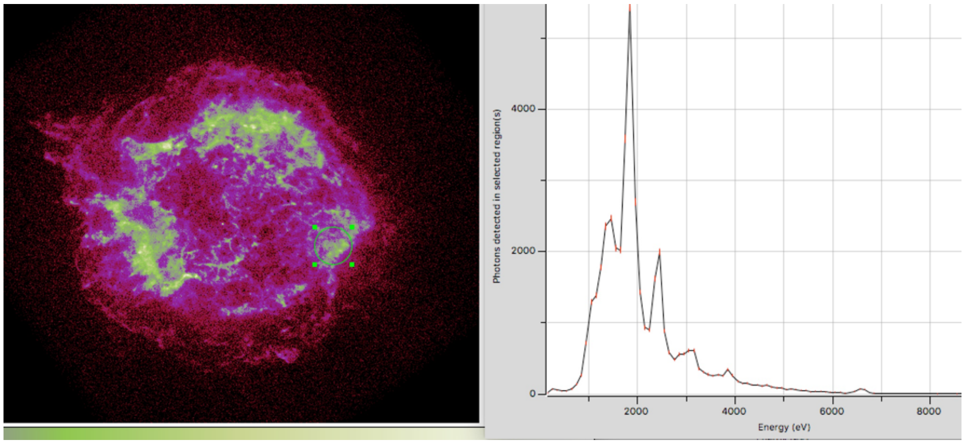

Image 39

Question 22.

(a) X-ray images are always displayed in "false-color", since the eye is not sensitive to x-rays. You can choose any "color-map" you wish to display the data.

(b) The peaks correspond to emission from different atomic species.

(c) The remnant is not hot enough to produce much radiation beyond 7 keV.

(d) The spectra are quite different, with one displaying enhanced emission at about 1 keV, corresponding to the element iron. (There are other atomic species also present at 1 keV, but iron is dominant here.)

(e) The explosion was not uniform (which is usually what we assume in our models). Our knowledge of the exact nature of supernova explosions is really quite primitive.