Lab 10 / Supernova Remnants (SNR): Dimensions and Expansion Rates

Name: _____   **Score:** _____

◢Summary

The student will use CCD images of the Crab Nebula and a Hubble Space Telescope image of SN1987a to examine a number of characteristics of supernovae and their remnants.

◢Background and Theory

Supernova explosions are the most powerful events in the universe. In less than a second, about 10^{44} joules of energy are released—about the same as the Sun has released in its entire lifetime! The explosion results from the death of a massive star which has consumed its entire fuel supply. The apparent magnitude of a supernova brightens by about 10 magnitudes within a few hours, and for a few months the luminosity of the star is comparable to the luminosity of the entire parent galaxy.

Supernovae are rare events, occurring only once or twice per century in a typical galaxy. There have been just six supernovae seen in the Milky Way in recorded history, with the most recent occurring in 1604, just before the advent of telescopes. The perceptive reader will notice that this rate is much less than the rate of one or two per century reported above (which gives ~20–40 in 2000 years). At visible wavelengths, we cannot see very far into the disk of our galaxy due to light extinction by dust. Therefore, a supernova must be quite close (within ~4 parsecs) to be observed. The 1–2 per century rate is based on average detection rates in galaxies other than our own in which we can see the galactic disk face-on with little extinction.

M1, Crab Nebula

Supernovae are classified into two broad categories, based on their light curves (brightness vs. time). Type I supernovae rise sharply to a maximum, and decay gradually, whereas Type II supernovae rise and decay more gradually. Type II can be sub-divided into IIL (linear decay) and IIP (plateau decay). The figure below is a sketch of the three types of light curves.
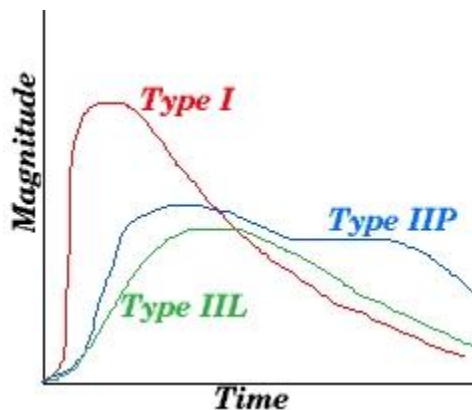
The spectra of the two main types of supernovae also differ. Type II spectra show mostly hydrogen lines, while Type I spectra have lines of many elements. The progenitor star of a Type I supernova is thought to be a Population II white dwarf in a binary system with a red giant companion. Mass from the red giant accretes onto the white dwarf until the dwarf's mass passes the Chandrasekhar limit of 1.44 solar masses. The dwarf then collapses violently and becomes a Type I supernova. The progenitor star for a Type II supernova is thought to be a Population I massive red (or blue) supergiant. After the star ceases nuclear fusion, gravity takes over and compresses the star to a very small diameter. This implosion causes a shock which bounces off the core, resulting in an explosion which we see as a Type II supernova. The shock carries of a large fraction of the stellar atmosphere at speeds of 13,000–30,000 km/s.

In this exercise, you will study two supernovae:

▶ The Crab supernova (SN1054 in Taurus) is probably the most well-known and best studied of all supernovae. It resulted from a stellar explosion in 1054 AD and was widely reported in the historical records of Chinese and Japanese court astronomers. Although the explosion took place about 2000 pc away, it was visible for about a month in the daytime sky. Even today the Crab supernova remnant is the brightest object in the sky at X-ray wavelengths. Optically, it is fairly dim (visual magnitude is ~10), but it is a beautiful object when imaged with large telescopes.

▶ Supernova SN1987a was the first "nearby" supernova to be observed since the invention of the telescope. This supernova occurred 50 kpc away in the Large Magellanic Cloud. At peak brightness, it reached 2nd magnitude and was featured on the cover of *Time* magazine. This supernova was only visible from the Southern Hemisphere.

◢Part A: The Expansion Speed of the Crab Supernova Remnant [36 pts]

Procedure [**Note rounding instructions!**]

1. Measure the average diameter, *d*, of the Crab Supernova Remnant (SNR) in pixels by taking a measurement along the long axis and the short axis and then averaging the two measurements. Use the on-screen measurer to determine pixels (to 2 decimal places). (Go to **http://www.astro.washington.edu/101-bin/sn/imgmeas?crabneb**) NOTE: **This link is now broken.** Use the values shown in the blanks below. (**Round part c to 2 decimal places.**) [3 pts]

2. The pixels in the image have an angular size of 1.2 arcseconds per pixel. Convert the diameter of the Crab to arcseconds using this conversion factor. This is the angular size alpha, *a*. (**Round answer to 1 decimal place.**) [4 pts]

3. The distance, *D*, to the Crab SNR is about 2000 pc. You can use the small angle formula:

$$d = (D \times a) / 206265''$$

to find the actual size (diameter), *d*, of the Crab in parsecs (pc). Convert this size to AU and then to kilometers. Use the following conversion factors: 1 parsec (pc) ≈ 3.09×10^{13} km ≈ 3.26 light-years; 1 AU ≈ 1.496×10^8 km. Use powers of ten notation for numbers over 10,000 (10^4). (**Round parts a, b, and c to 1 decimal place.**) [9 pts]

4. Assume that the expansion speed of the remnant has been constant since it was formed. You can calculate the expansion speed of the remnant by dividing the radius of the nebula in kilometers (km) by the age in hours. (Round to 1 decimal place and use powers of ten notation.) Remember that the radius is ½ the diameter. (First, calculate the age in years from 1054 AD to the present and then convert years to hours. Assume 365.25 days in a year.) Compare this speed to other speeds you know, such as the speed of a car on the highway (≈ 120 km/hr). Round (a) to 1 decimal; express (b) without powers of ten notation; round (c) and (d) to 2 decimals; round (e) to 1 decimal or write out answer without powers of ten notation. (**Round hours in a year to 3 decimals.**) [20 pts]

Answers [Ⓟ means USE scientific notation, i.e., powers of ten; if symbol is *not* present, write numbers normally]

1. (a) Diameter along LONG axis: **308.58 pixels**   (b) Diameter along SHORT axis: **225.21 pixels**

   (c) Average of the two diameters: _____ **pixels**

2. *a* = _____ **arcseconds**

3. (a) *d* = _____ **parsecs**   (b) *d* = _____ **km** Ⓟ   (c) *d* = _____ **AU** Ⓟ

4. (a) radius of Crab Nebula in km: *r* = _____ **km** Ⓟ [Remember that the radius is ½ the diameter.]

   (b) age in YEARS from 1054 to 2006: _____ **yrs**

   (c) age in HOURS from 1054 to 2006: _____ **hrs** Ⓟ (Calculate hours in a year: _____ **hrs/yr** Ⓟ)

   (d) Expansion speed of the supernova remnant: *v* = _____ **km/hr** Ⓟ

   (e) How many <u>times</u> faster than the speed of a car (120 km/hr) is the Crab expanding? _____ **X**
       (You can express this number in either scientific notation or as a "regular" number.)

◢Part B: The Age and Inclination of SN1987a [64 pts]

Procedure [**Note rounding instructions!**]

In this image taken by Hubble Space Telescope, you can see the supernova 1987a. This image was taken prior to the repair mission in 1993. You can see two bright stars, plus a third surrounded by a ring of material. This ring was shed from the outer layers of the blue supergiant star Sanduleak–69 202 million years prior to the supernova explosion, as the star evolved from a red supergiant.
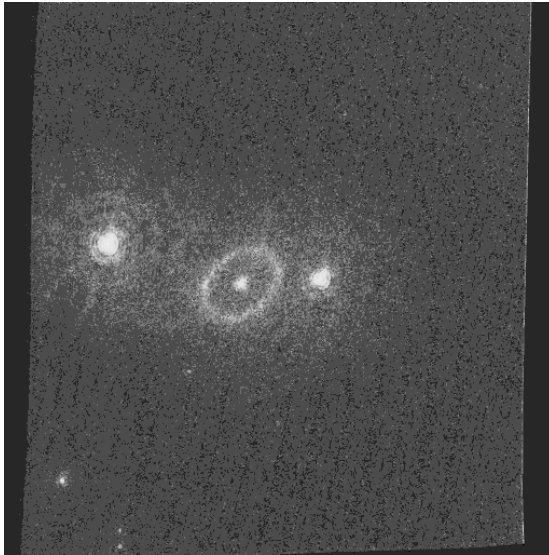
SN1987a

1. Measure the true linear diameter of the ring (in pixels). Be sure to measure at the widest part of the ring (long axis), since it is actually circular, and you are viewing it at an angle. (Pixels are given to 2 decimal places; do not round.) The link is now broken, so use the value provided in the blank below.

2. Convert this linear diameter (in pixels) to an angular size (in arcseconds) by multiplying by the image scale: **0.025 arcseconds/pixel**. Give the radius of the ring in arcseconds. **(Round to 2 decimal places for parts a and b.) [8 pts]**

3. Use the small angle formula— $d = (D \times a) / 206265''$ —to find the actual size of the ring first in parsecs and then in kilometers. The distance, D, to the ring is $\approx$ 50,000 pc. (Remember, the formula gives you a distance, d, in parsecs. You then have to convert parsecs to kilometers.) **(Round to 2 decimals for parts a–d.) [12 pts]**

4. Assuming that the ring was shed at a velocity of about 20 km/s, as is typical of red supergiant winds, how long ago was this ring shed from the central star? (Don't forget to use the *radius* instead of the diameter for this calculation!) Your answer will be expressed in years. Express this answer in regular numbers (not in powers of ten notation). **(Note: For seconds per year, round to 2 decimal places.) [5 pts]**

5. From the ratio of the smallest to the largest widths of the ring, estimate its inclination to our line of sight, i. **(For part b round to 3 decimal places; for part c round to 2 decimal places; for part d round to 1 decimal place.) [9 pts]**

   $$i = \sin^{-1}(smallest / largest)$$

   (You need a scientific calculator—available in Windows accessories—to compute the inverse sine.)

6. The shock wave itself is not luminous enough to be seen optically in this image. Ultraviolet spectroscopy was used shortly after the explosion to detect carbon IV transition lines. The rest wavelength, l_0, of carbon IV is 190.4 nm. The carbon IV line was recorded with Doppler shifts, dl, of up to 19.6 nm. Use the Doppler equation:

   $$v/c = dl/l_0$$

   to find the velocity, v, of the shock wave. Recall that the speed of light, $c = 3 \times 10^5$ km/s. **(Round a to 1 decimal place.) [6 pts]**

7. Given the speed of the shock wave and the ring's linear size which you have obtained, calculate how long it took the shock wave to reach the ring after the explosion occurred. The first pictures of this collision were taken in February, 1998. How close was your calculated estimate? What are possible sources of any discrepancy? [Hint: Think about how the ring looks to us.] **[24 pts]**

Answers   [⑰ means USE scientific notation, i.e., powers of ten; if symbol is *not* present, write numbers normally]

1. True <u>diameter</u> of ring: **78.75 pixels**

2. (a) Angular <u>diameter</u> of ring: _____ **arcseconds**   (b) <u>Radius</u> of ring: _____ **arcseconds**

3. (a) True <u>diameter</u> of ring: _____ **parsecs**   (b) <u>Radius</u> of ring: _____ **parsecs**

   (c) True <u>diameter</u> of ring: _____ **km** ⑰   (d) <u>Radius</u> of ring: _____ **km** ⑰

4. Age of ring: _____ **years** [Calculate seconds in a year: _____ **s/yr** ⑰]

5. You have already determined the <u>largest</u> width (diameter) of the ring in parsecs. Write that value here: _____ **parsecs**

   (a) Using the online measurer, determine the <u>smallest</u> width (diameter) of the ring: **53.76 pixels**

   (b) Convert pixels in (a) to arcseconds: _____ arcseconds

   (c) Use the small angle formula to calculate the smallest width (diameter) in parsecs: _____ **parsecs**

   (d) Substitute the value for the largest width (in pc) and the smallest width (in pc) into the inclination formula and calculate *i*.
      Note that $\sin^{-1}$ is the inverse sine function. [<u>Hint</u>: Your answer will be greater than 10º but less than 50°.]

      $i =$ _____ °

6. Rest wavelength, l_0, of carbon IV is 190.4 nm. The Doppler shift, *dl*, is 19.6 nm. Remember that $c = 3 \times 10^5$ km/s. Calculate *v*.

   (a) $v_{shockwave} =$ _____ **km/s** ⑰ [**Express as powers of ten notation; round to 1 decimal place.**]

   (b) $v_{shockwave} =$ _____ **km/s**   [**Express <u>without</u> using powers of ten notation.**]

7. First pictures of the collision were taken in February 1998 (Use Feb 1 as your end date.) The repair mission occurred in December 1993. Use November 1, 1993 as the date for the image of the ring you are working with.

   (a) Time between image used in this lab (November 1, 1993) and the first pictures of the collision (February 1, 1998):

      _____ **years** _____ **months** [<u>Hint</u>: You will need to convert this to **decimal notation** for part e.]

   Speed of shockwave = _____ **km/s** ⑰ [Copy from question 6.]

   Distance to ring (its radius) = _____ **km**   ⑰ [Copy from question 3.]

   (b) r_{ring} / $v_{shockwave} =$ km / km-s^{-1} = s = _____ **s** ⑰ [This is the time it took the shockwave to reach the ring.]

   (c) seconds in a year: _____ **s/yr** ⑰ [From question 4. Use this value to calculate the time in years.]

   (d) Time for shockwave to reach ring: _____ **years** [**Express in decimal notation.**]

   (e) How close was your calculated estimate? My estimate is _____**%** of the value determined in part (a).
      [<u>Caution</u>: If your estimate (*answer d*) is greater than *answer a*, will your percentage be greater or less than 100%? Answering this question will tell you which value to divide into the other.]

   (f) What are **two** possible sources of discrepancy ***NOT*** related to errors measuring the images or calculator errors? [<u>Hint</u>: Think about the speed of expansion—does it vary?—and the view we have of the ring from our perspective here on Earth.]

   ①_____

   _____

   ②_____

   _____