Laboratory Exercise in Astronomy
The Crab Nebula.

You should bring this offprint with you to the lab. Read the exercise and use the worksheet below to answer questions posed in the exercise. Throughout the lab, express your answer with the number of decimal digits indicated, and keep in mind what you estimate is the magnitude of errors in your measurements.

(1) Establishing the scale for each photograph. The two stars marked in the two photographs of the Crab Nebula are 385 arc seconds apart. To determine the scale (arc seconds per mm) of the photographs, use a ruler to measure the distance between the two stars and divide this value into the angular separation between the stars.

distance (expressed to nearest 0.1 mm) between marked stars:

1973 photo mm 2000 photo mm

scale (seconds of arc per millimeter, expressed to nearest 0.001 arcsec / mm):

1973 photo arcsec / mm 2000 photo arcsec / mm

(2) Distance from pulsar to stars −−checking your procedure. After identifying the pulsar in each of the images, use the ruler to measure the distance between the pulsar and five stars located near the outer edge of the nebula. Convert this distance to angular separation using the photograph scales determined in step 1, noting that each photograph may have a slightly different scale.

distance from pulsar to stars:

	separation (mm; to nearest 0.1 mm)		angular separation (arc seconds; to nearest 0.1 arcsec)		
star	1973 photo	2000 photo	1973 photo	2000 photo	difference ('00−73)
1	________	________	________	________	________
2	________	________	________	________	________
3	________	________	________	________	________
4	________	________	________	________	________
5	________	________	________	________	________

Compare the angular separation results for the five stars. [Note, repeat the measurement if your differences are greater than 2 arc seconds.] Do the 1973 and 2000 values agree to within your estimated measurement error? Would you expect the 1973 and 2000 pulsar–star separations to be the same? Why or why not? Briefly discuss any discrepancies –– how large are they and to what do you attribute them.

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(3) Distance from pulsar to knots in supernova remnant. Now that you understand the magnitude of measurement errors that you can expect in measuring the separation between two objects on the photographs and have determined that the pulsar is not moving quickly relative to the background stars, you will measure the distance between the pulsar and five filaments along both the major and minor axes. Select filaments near the outer edge of the nebula. Convert the distance (in millimeters) to angular separation (in arc seconds) as you did in the previous table.

distance from pulsar to knots in supernova remnant:

	separation (mm; to nearest 0.1 mm)		angular separation (arc seconds; to nearest 0.1 arcsec)		
star	1973 photo	2000 photo	1973 photo	2000 photo	difference ('76–'42)
roughly along major axis					
1	________	________	________	________	________
2	________	________	________	________	________
3	________	________	________	________	________
4	________	________	________	________	________
5	________	________	________	________	________
roughly along minor axis					
6	________	________	________	________	________
7	________	________	________	________	________
8	________	________	________	________	________
9	________	________	________	________	________
10	________	________	________	________	________

Comment on the differences between the 1973 and 2000 knot positions in light of the scatter you found in step 2 when you measured star positions. Do you believe that the knot motions are real or due to measurement errors? Is there a difference between the knot motions roughly along the major axis as compared with those along the minor axis? Why do you think this is so?

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(4) Determining the proper motion of the knots and estimating the time since the supernova explosion. The proper motion, μ, of the knots is calculated by dividing the angular difference, Δx, between the 1973 and 2000 separation of the pulsar and a knot which you determined in the fifth column in step 3 by the time interval ($\Delta t = 27$ years) between the photographs. $\mu = \Delta x / \Delta t$. The proper motion is given in units of arc seconds per year.

If you know the angular separation between the pulsar and a knot in 2000 (the fourth column in step 3) and the rate at which the knot is moving away from the pulsar (the proper motion, μ), then you can calculate the time elapsed since the knot was coincident with the pulsar position. This time corresponds to the time of the explosion.

knot	angular change Δx (arc sec) (to nearest 0.1)	proper motion μ (arc sec / year) (to nearest 0.001)	pulsar–knot angular separation (arc sec) (to nearest 0.1)	time since explosion (T) (years) (to nearest 10)
major axis:				
1	________	________	________	________
2	________	________	________	________
3	________	________	________	________
4	________	________	________	________
5	________	________	________	________
minor axis:				
6	________	________	________	________
7	________	________	________	________
8	________	________	________	________
9	________	________	________	________
10	________	________	________	________

From the five values along the major axis for the time since the explosion, determine the median value (middle of the five numbers) for the time since the explosion:

______________ years

and use this value to estimate the date of the explosion: ______________ AD

From the five values along the minor axis for the time since the explosion, determine the median value (middle of the five numbers) for the time since the explosion:

______________ years

and use this value to estimate the date of the explosion: ______________ AD

How do these estimated dates compare with the 1054 AD date of the observed supernova explosion? Be sure to discuss why your answer differs.

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(5) Finding the distance to the nebula. To determine the distance to the supernova remnant you will use a technique frequently used by astronomers to estimate distances −−assuming that the spatial velocity of all the knots is the same and equating linear velocity of knots whose motion is primarily in the plane of the sky to the radial velocity of knots whose motions are primarily toward or away from us.

To determine the radial velocity of some knots, you need to measure the scale for the spectroscopic plate:

center−to−center distance between 3690A and 3799 A lines:

________ mm (to nearest 0.1) ====> ____________ A/ mm (to nearest 0.1)

Determine the maximum wavelength shift, $\Delta\lambda$, in the knot spectra using this conversion factor:

________ mm (to nearest 0.1) ====> $\Delta\lambda$ = _______________ (to nearest 0.1)

From the observed wavelength shift, calculate the radial velocity (show your work):

$v = (1/2)\ (\Delta\lambda\ /\lambda)\ c$ = ____

= ___________________ km/sec (to nearest 10)

Using the median value for the proper motion of knots near the end of the minor axis (see your work just after the table in step 4):

m = ______________________ arc seconds / year (to nearest 0.001)

The distance to the Crab Nebula can then be calculated from the equation relating distance, tangential velocity and proper motion:

$d = 0.69\ \nu/\mu$

where the distance d is expressed in light years, the tangential velocity, ν, is expressed is in units of km/sec, and the proper motion, μ, is in units of arc seconds / year. Calculate the distance to the nebula (show your work):

$d = 0.69\ \nu/\mu$ = ____________________________

= _______________ light years (to nearest 10)

Comment on how your calculated distance compares with the accepted value of 6500 light years (2000 parsecs). Briefly discuss your result and any discrepancies.

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(6) Summary. Briefly comment on what you learned in this lab and conclusions that you can make from your results. Discuss both the procedures and science that you learned.