Supernovae & Supernovae Remnants

Summary

Supernovae and their remnants will be investigated together with their usefulness as techniques in distance determination.

Background

A massive star having consumed its entire fuel supply will suddenly die in a spectacular explosion, releasing in about one second the energy equivalent to the total energy output by the Sun during its lifetime. Within a few hours the apparent magnitude of a supernova brightens by about 10 magnitudes and for a few months the luminosity of the star is comparable to the luminosity of its parent galaxy.

Supernovae events are rare in a galaxy, typically occurring with a frequency of only once or twice per century. The observed rate in our own Galaxy (six in recorded history) is much less than this expected rate of one or two per century (20-40 in 2000 years). Seeing very far into the disk of our Galaxy at visible wavelengths is hampered due to light extinction by dust, thus limiting supernovae detection to those located within about 4 parsecs. Average detection rates for typical galaxies are based on observations of face-on galaxies that suffer little extinction.

Supernovae can be classified by their light curves. The Type I supernovae light curve rises sharply to a maximum, and then decays gradually. The progenitor star of a Type I supernova is thought to be a Population II white dwarf in a binary system that is accreting mass from its red giant companion. When the white dwarf mass exceeds the Chandresekhar limit of 1.4 solar masses it collapses violently and becomes a Type I supernova.

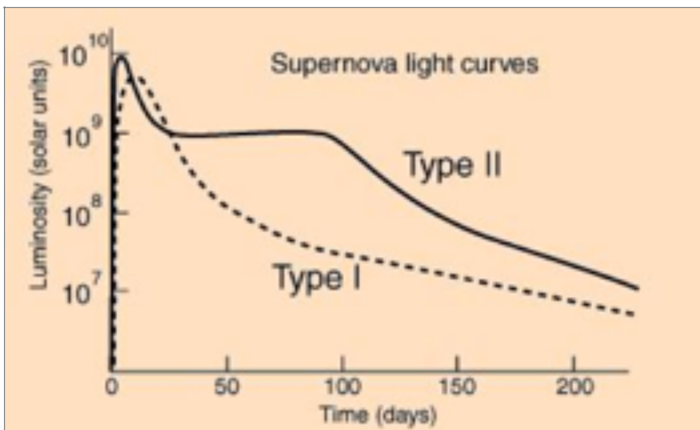


Figure 1: Supernovae Light Curves

The Type II supernovae light curve rises and decays more gradually than the Type I light curve.
Type II can be subdivided into IIL (linear decay) and IIP (plateau decay).

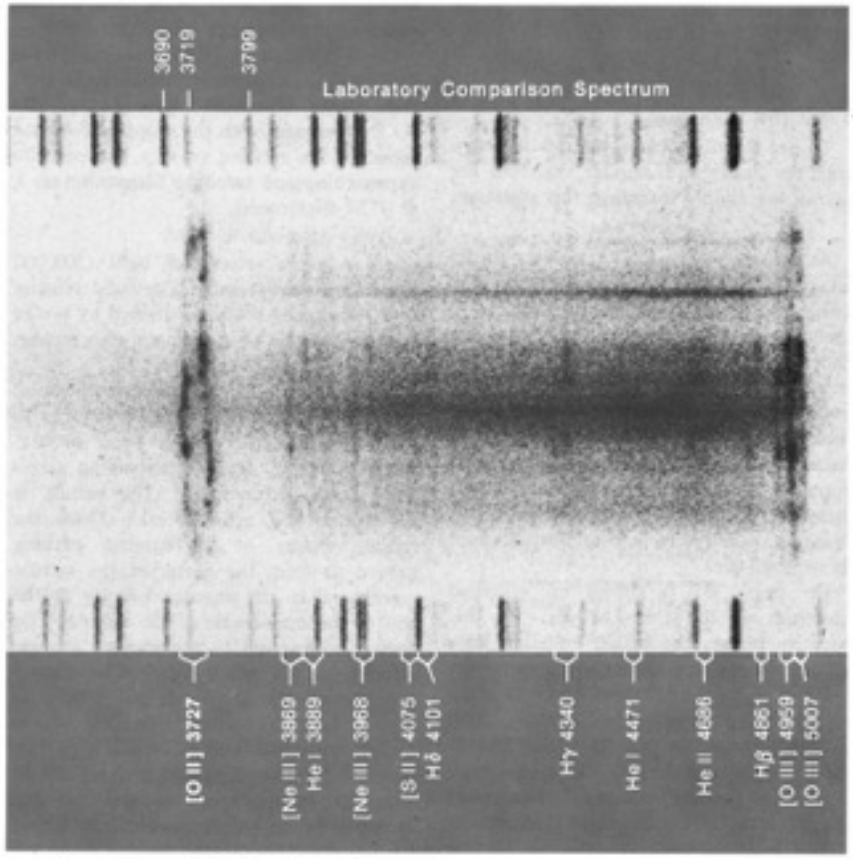
The progenitor star for a Type II supernova is thought to be a Population I massive red (or blue) supergiant. When fuel is no longer available for nuclear fusion, the star implodes, causing a shock that bounces off the core, resulting in a Type II supernova explosion that carries off a large fraction of the stellar atmosphere at speeds of 13,000-30,000 km/s.

Supernovae of type Ia can be used as standard candles, that is, their peak brightness are consistently confined to a small range of absolute magnitude (-19.46 $\pm$ 0.56 in the B band). Since they are so bright they can be used to determine cosmological distances via the appropriate form of the familiar relation: **m-M=5 log R –5**. Observations of Type Ia supernovae made by the Supernova Cosmology Project suggested that the expansion of the universe was accelerating and thus provided the most direct evidence for dark energy.

Part A: The Nebular Expansion Method (Age & Distance Determination)

The Crab supernova remnant (SN1054 in Taurus) is probably the most well known and best studied of all supernovae remnants. The Chinese and Japanese historical records of court astronomers indicate that in 1054 AD a supernova was visible for about a month in the daytime sky. Today the remnant is relatively easily seen in a small telescope (as the alternate catalogue designation M1 would suggest).
There are two images of the Crab Nebula one taken in 1973 and the other in 2000. Notice how they differ.

1. Measure the average radius of the Crab Supernova Remnant in millimeters.
2. Determine the plate scales and convert the measured radii to arcseconds. Use the stars labeled "A" and "B" to determine the plate scale. These two stars are separated by 6.45'.
3. Determine the average angular velocity μ of expansion of the nebula in “/yr.
4. Determine the age of the nebula and give an estimate of the uncertainty in your result, indicating how you arrived at it. How does your computed age compare with the historical record? What assumptions had you made in your determination?
5. Determine the velocity of expansion of the nebula from the spectrogram. The distance (ly) to the nebula is given by: $D = 0.69\ v/\mu$.
6. How well does your answer compare to the accepted value of 6.3 kly?
7. Find the actual size of the Crab in pc. (Remember d=(D*a)/206265")



The spectrum of the Crab nebula, obtained at Lick Observatory by N. U. Mayall with the Crossley reflector. The spectrograph slit was aligned with the major axis of the nebula (here vertical), to record velocity differences along that axis. These are best shown by the necklace shape of the 3727-angstrom oxygen line. A laboratory spectrum of palladium, tin, and lead flanks that of the Crab to give a wavelength scale; nebular lines are identified at bottom.

Part B: SN1987a

In this image taken by Hubble Space Telescope, you can see the supernova 1987a. 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 prior to the supernova explosion as the star was evolving.

1. Measure the true linear diameter of the ring.
2. Convert this linear diameter to an angular size using an image scale indicated.
3. Find the actual size of the ring in light years. The distance, D, to the ring is about 50 kpc.
4. If typical red supergiant winds have velocities of about 20 km/s, how long ago was this ring shed from the central star? From the ratio of the minor to the major axis of the ring, estimate its inclination I to our line of sight,

$$d_{minor}=d_{major} \times \sin i$$

5. The shock wave motion is evident in the ultraviolet carbon IV transition lines. The rest wavelength, λ_0, of carbon IV is 190.4 nm. The carbon IV line was recorded with Doppler shifts, $\delta\lambda$, of up to 19.6 nm. Find the velocity v, of the shock wave using:

$$v/c=\delta\lambda/\lambda_0$$

6. Given the speed of the shock wave and the ring's linear size, 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 estimate? What are possible sources of any discrepancy?

Part C: Supernovae as Standard Candles

If the Crab supernova was visible in the daytime sky for a few months how would you go about determining the distance to it? Give an estimate.

References: *University of Washington: Introductory Astronomy Clearinghouse Labs*

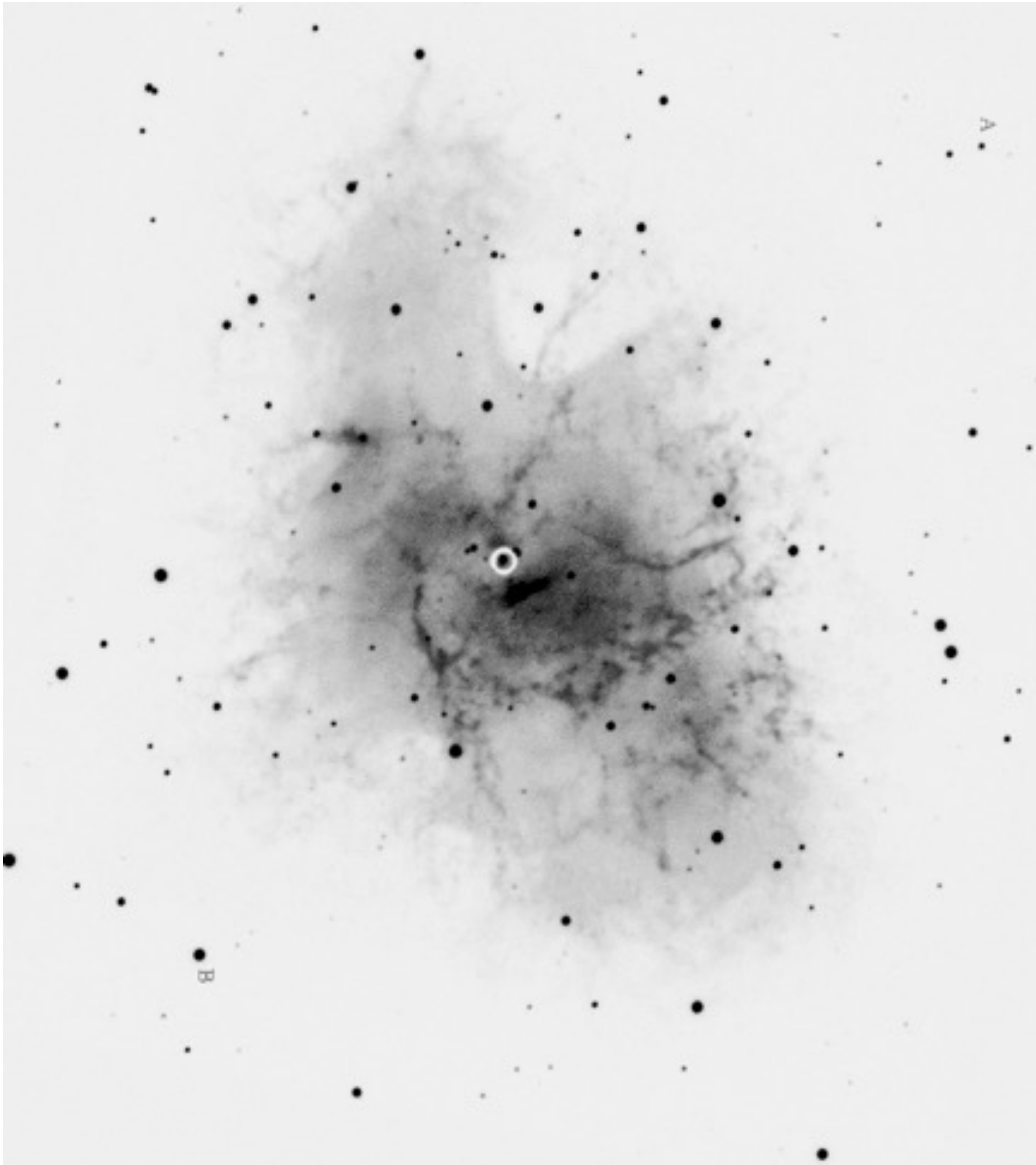


Figure 2: M1 in 1973. The pulsar has been circled in white.

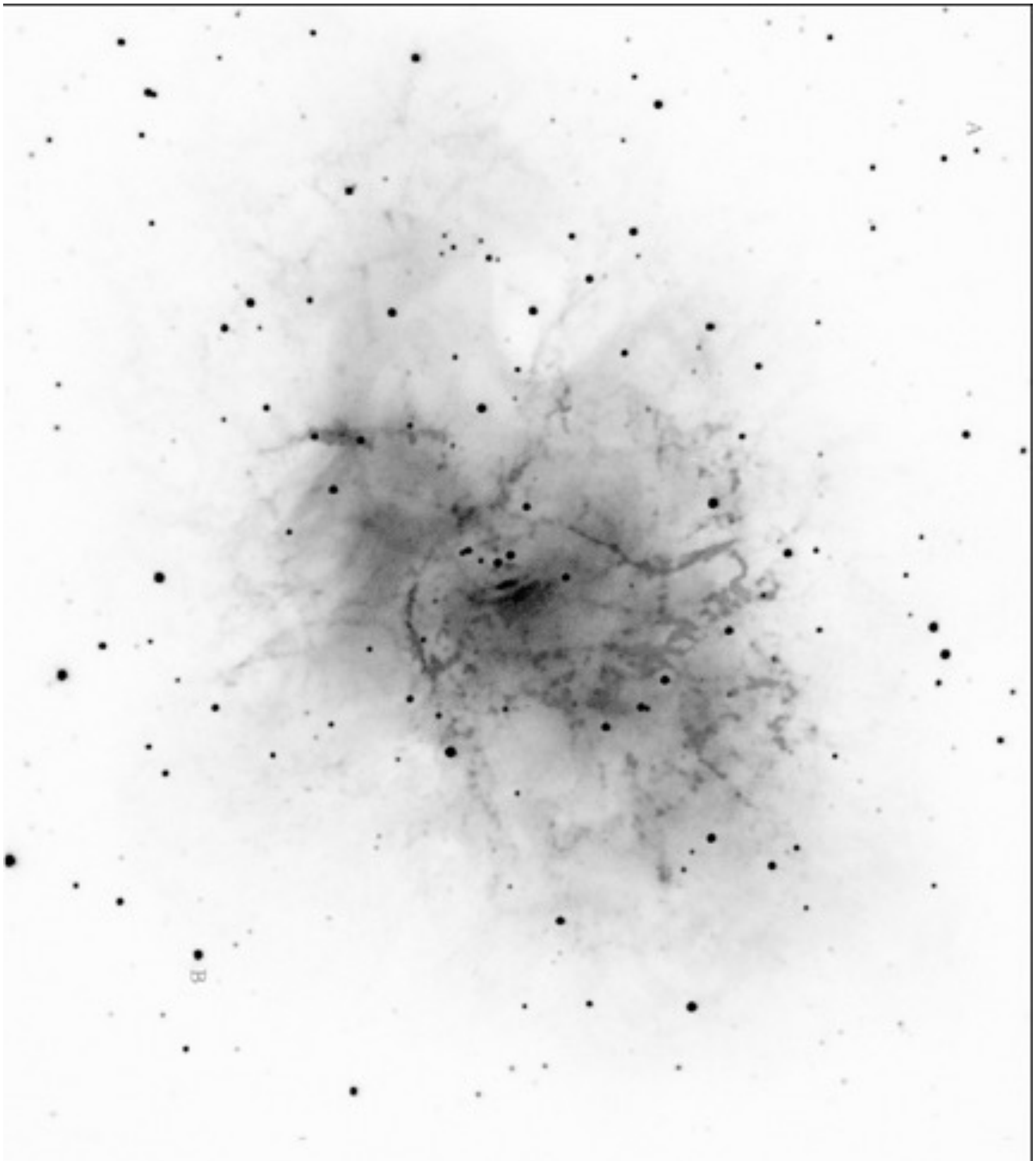
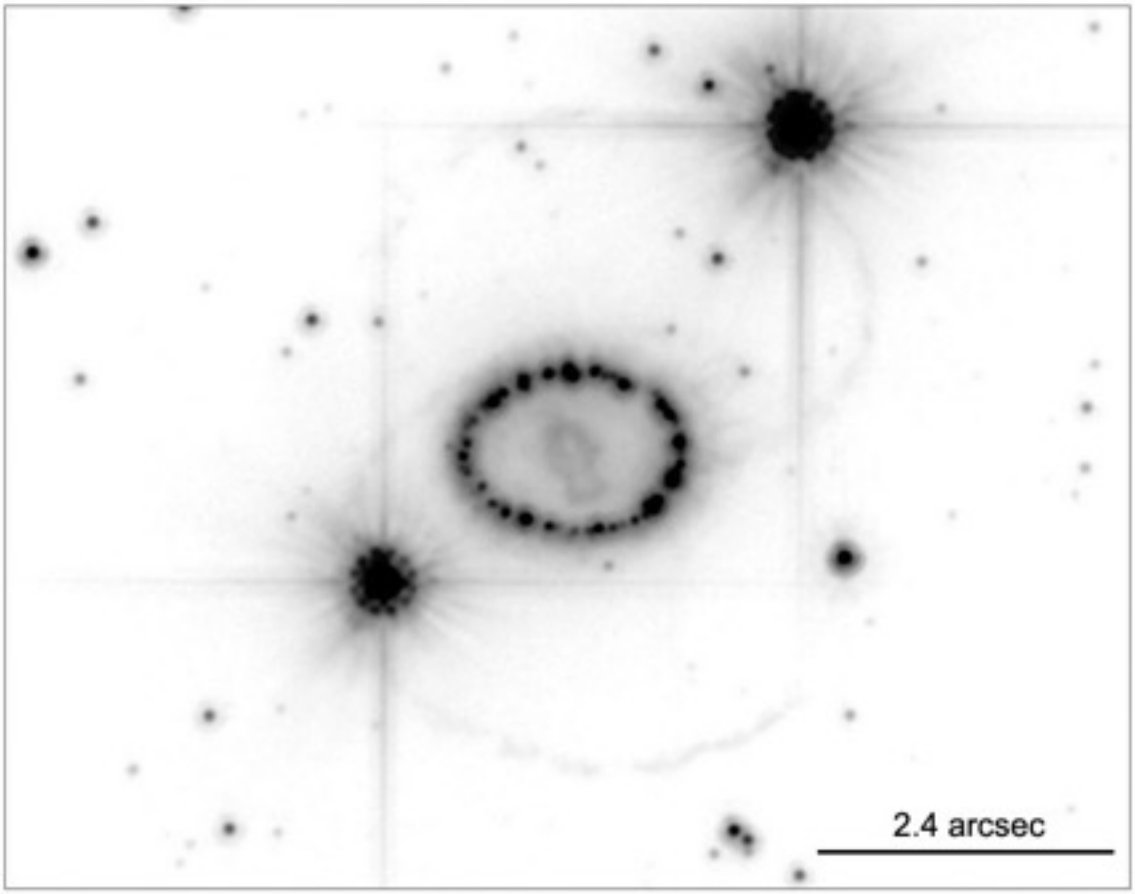


Figure 3: M1 in 2000



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Hubble Space Telescope • Advanced Camera for Surveys

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