# TYPE I SUPERNOVAE: AN OBSERVER'S VIEW

Robert P. Kirshner
Department of Astronomy, University of Michigan

To an observational astronomer, a supernova is a new star of extremely high luminosity ($L > 10^8 L_\odot$). Generally these objects are discovered through supernova searches that use small Schmidt cameras to obtain repeated photographs of external galaxies, although they are sometimes discovered by chance as astronomers study other galaxies, and in historical times a handful have been sighted in our own galaxy (see Clark and Stephenson, 1978).

At the present, about 5 to 10 supernovae are discovered each year, and the total number since 1885 amounts to nearly 400 (Kowal, 1980). Each supernova is given a name that consists of the year of discovery, followed by a letter that indicates the order of discovery. Hence 1972e was the 5th supernova discovered in 1972. An important bibliographical source of information on individual supernovae is the compilation by Karpowicz and Rudnicki (1968). Two recent conferences on supernovae are also of general utility: see Cosmovici (1974) and Schramm (1977).

It is important to keep clearly in mind that the supernovae, in the sense of large optical outbursts, are not necessarily linked one-to-one with stellar deaths, pulsar formation, or the creation of black holes. Although a massive star is not likely to end its nuclear burning in a peaceful way, the optical outburst depends on the properties of the outside of the star. It is quite likely that some stars collapse to form compact stellar remnants, but release their energy at other wavelengths and are not counted as supernovae.

The classification of supernovae into types is a spectroscopic classification defined by a few prototypes in each class (Zwicky, 1968, Oke and Searle 1974). It is not defined by the shape of the light curve (luminosity vs. time) or by the type of galaxy in which the supernova erupted. For Type I, the prototypes are SN 1937c in IC 4182 (Minkowski, 1939, Greenstein and Minkowski, 1973) and SN 1972e in NGC 5253 (Kirshner et al. 1973 a, b, Kirshner and Oke, 1975.) In each of these cases, a supernova was discovered in a nearby galaxy and then observed frequently until it grew too faint for the best available detectors on the largest telescopes. In the case of 1972e, some spectroscopic data were obtained nearly two years after the explosion when the object was fainter than m = 21. An important difference between the 1937 data and the 1972 data is that the modern spectra are obtained photoelectrically rather than with photographic plates. This permits measurements to be made over a wide wavelength range from 3200 Å to 11000 Å and it also allows the data to be calibrated in absolute values of flux density: erg $cm^{-2}s^{-1}Å^{-1}$.

ISSN:0094-243X/80/630033-05$1.50 Copyright 1980 American Institute of Physics

In the 1972 data, the spectral resolution was no better than 20 Å and typically 40 or 80 Å. With current detectors, such as image dissectors, reticons, and vidicons it is possible to obtain the energy distribution of a supernova at 5-10 Å resolution over a span of about 3500 Å.

Some important qualitative results have emerged from the 1972 work that have had considerable impact on models for Type I supernovae. First, near maximum light most of the energy is carried in a continuum which looks very much like the energy distribution of a supergiant star. This continuum, which has an effective temperature near 12,000 K at maximum light (Kirshner, Arp, and Dunlap, 1976) cools to around 7000 K after a few weeks. During this epoch, the photosphere expands as the temperature drops. The expanding photosphere has a velocity near 10,000 km $s^{-1}$, a fact which indicates that supernovae really do explode, and which has been used to estimate the distance of extragalactic supernovae.

The distance estimate (Branch and Patchett, 1973, Kirshner and Kwan, 1974) comes from comparing the angular rate of expansion, as inferred from the photospheric temperature and the received flux measured at several epochs, with the linear rate of expansion as inferred from spectral lines. It is important to develop a correct picture of the expanding atmospheres of the supernovae in order to refine this distance estimate, since it is an extragalactic method that does not depend on the usual chain of methods leading from the distance to the Hyades through the calibration of the Cepheids and beyond.

With regard to the spectral lines observed near maximum light, a few appear to be the same lines that are present in SN II: Ca II, K and H, the Ca II infrared triplet, the Na I D lines (or pherhaps He I λ5876), and the Mg I b band. In SN II, the lines appear to form smaller excursions from the continuum than in SN I: this may result from SN I's having more line-forming ions compared to the source of continuum opacity. If the continuum opacity comes from electron scattering, this may just be a reflection of a low hydrogen abundance.

The most conspicuous difference between SN II and SN I lies in the strength of the hydrogen lines. In SN II, Hα and Hβ are clearly present, and very strong. In SN I, they may be entirely absent, and in any event are rather weak.

Most of the strong lines in SN atmospheres are present both in absorption and in emission. Generally, a violet-shifted absorption trough extends out to blue shifts of ~15,000 km $s^{-1}$ or more, while an emission peak is generally observed near and to the red of the rest wavelength of a line. This is the type of line profile observed in ordinary stars that have substantial mass outflow: they are called P Cygni lines after the prototype star. Physically, P Cygni lines arise in an expanding atmosphere that scatters, but does not absorb, photospheric photons.

The problem of line identifications in SN I near maximum light is made complex by overlapping emissions and absorptions. Models by Branch overcome some of this confusion by synthesizing large regions of the spectrum rather than concentrating on individual features. Doing this correctly requires large amounts of atomic data on low-lying levels of low ionization stages for common elements.

At late times, after the continuum has faded into insignificance, the spectra of SN I are dominated by four broad bands of emission at $\lambda$4200, 4600, 5000, and 5300. The famous exponential decay in the light curve of SN I in blue light is an observation that refers to the behavior of this complex. In 1975, Kirshner and Oke suggested that [Fe II] lines, lots of them, might blend together to form some of these emission bands. Refinements of that idea are presented in this conference by Meyerott and by Axelrod.

The really tempting idea that SN I synthesize iron-peak nuclei that provide energy through radioactive decay _and_ can be observed in the spectrum at late times requires more stringent observational tests. As a small contribution to the discussion, I have compiled a table which gives a good estimate of the energy emitted by an SN I as a function of time. Near maximum light ($t \leq 46$ days), I have integrated under the blackbody that best fits the spectrum in the range 3300 - 11, 000Å. Since this wavelength range includes the peak of the blackbody curve, and there is no clear indication of large fluxes in the ultraviolet (Holm, Wu, and Caldwell, 1974) or infrared (Kirshner _et al_. 1973b), this seems reasonable.

At later times, a blackbody is a very poor representation of the spectrum. Since there is no sensible way to include flux that is outside the observed wavelength region, I have merely summed the received energy from 3000 - 11, 000 Å. Each data point should be good to about 20%.

I have used distances of 45 Mpc for NGC 2207 (SN 1975a; Kirshner, Arp, and Dunlap 1976) and 4 Mpc for NGC 5253 (SN 1972e). If these distances are incorrect, then the emitted power is wrong by the square of the distance.

TABLE 1

SN I LUMINOSITY

| Age | | log L (erg $s^{-1}$) |
|---|---|---|
| days | $10^6$ sec | |
| | SN 1975a in NGC 2207 | |
| - 5 | -0.43 | 43.23 |
| - 2 | -0.17 | 43.28 |
| | SN 1972e in NGC 5253 | |
| + 14 | 1.21 | 42.94 |
| + 25 | 2.16 | 42.76 |
| + 36 | 3.11 | 42.32 |
| + 46 | 3.97 | 42.23 |
| + 82 | 7.1 | 41.9 |
| +206 | 17.8 | 40.8 |
| +237 | 20.5 | 40.5 |
| +349 | 30.2 | 39.9 |
| +418 | 36.1 | 39.5 |
| +716 | 61.9 | 38.3 |

Finally, let me make a suggestion to those who search for supernovae. I believe that the discussion at this conference demonstrates the importance of finding bright supernovae that can be followed intensively for long stretches of time. Obtaining ultraviolet, infrared, and better optical data on a new bright SN I will add more to the discussion than 100 new SN at the limit of spectroscopic study.

RPK's research on supernovae is supported by the National Science Foundation through grant AST 77-17600 and by an Alfred P. Sloan Foundation Research Fellowship.

# REFERENCES

Branch, D., and Patchett, B. 1973, M.N.R.A.S., 161, 71.

Clark, D. H., and Stephenson, F. R. 1977, The Historical Supernovae (Oxford: Pergamon).

Cosmovici, B. C. (ed) 1974, Supernovae and Supernova Remnants (Boston: Reidel).

Greenstein, J. L., and Minkowski, R. 1973, Ap. J., 182, 225.

Holm, A. V., Wu, C. C., and Caldwell, J. 1974, Pub. A.S.P., 86, 296.

Karpowicz, M., and Rudnicki, K. 1968, Preliminary Catalog of Supernovae (Warsaw: Warsaw Univ. Press).

Kirshner, R. P., Oke, J. B., Penston, M., and Searle, L. 1973a, Ap. J., 185, 303.

Kirshner, R. P., Willner, S. P., Becklin, E. E., Neugebauer, G., and Oke, J. B. 1973b, Ap. J. (Letters), 180, L97.

Kirshner, R. P., and Oke, J. B. 1975, Ap. J., 200, 574.

Kirshner, R. P., Arp, H. C., and Dunlap, J. R., 1976, Ap. J., 207, 44.

Kowal, C. T. 1980, Master List of Supernovae, Caltech.

Minkowski, R. 1939, Ap. J., 89, 143.

Oke, J. B., and Searle, L. 1974, Ann. Rev. Astron. Astrophys., 12, 315.

Schramm, D. N. (ed.) 1977, Supernovae (Boston: Reidel).

Zwicky, F. 1968, in Stars and Stellar Systems, Vol. VIII (Chicago: Univ. of Chicago Press).