SUPERNOVAE: THE ULTIMATE INSTABILITY

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Observed properties of supernovae and of very young supernova remnants provide important clues to answer the question, "which stars become supernovae?" There are three general lines of evidence (1) the statistics of supernovae, (2) the physical state of supernovae near maximum light, and (3) the chemistry of young supernova remnants. These lines of evidence appear to be converging on the view that all the supernova explosions we see, whether Type I or Type II, arise from the destruction of young massive stars.

It is important to note that supernovae fall into two distinct spectroscopic classes: Type I which does not show strong hydrogen lines, and Type II in which hydrogen emission and absorption is prominent (Oke and Searle, 1974). It is possible that the stellar progenitors of these two types are very different, but recent evidence suggests that the similarities in the properties of the two classes are more important.

(1) STATISTICAL ARGUMENTS

Arguments from statistics require the discovery and subsequent photometry and spectroscopy of supernovae. In the recent past, the fraction of supernovae for which the assignment of Type I or Type II can be made has risen sharply due to the energetic efforts of the Asiago group and work at the University of Michigan's McGraw-Hill Observatory. For Type II supernovae, the investigation by Maza and van den Bergh (1976) showed clearly that these supernovae are found only in the spiral arms of spiral galaxies. This implies that the stars go through their entire evolution before leaving their birthplaces. The stars that become Type II supernova must be massive stars with lifetimes less than 10^{7-8} years. Type I supernovae are the only kind seen in elliptical galaxies - they are also present in spirals and ellipticals. While it may seem natural to assume that SN I's come from long-lived and low-mass stars, the recent investigation by Oemler and Tinsley (1979) suggests just the opposite. By examining the numbers of SN I in irregular galaxies, and the connection between

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indicators of a galaxy's present star formation rate and its rate of SN I production, they conclude that at least some SN I come from short-lived stars with lifetimes of order 10^{7-8} year. The spectroscopic evidence is that SN I are a homogenieous class, so it seems plausible to suggest that all SN I arise from the same type of progenitor. The difficulty comes with the SN I in elliptical galaxies since the rate of SN I comes perilously close to the upper limits imposed by star formation rates in those galaxies.

(2) PHYSICAL ARGUMENTS

Spectrophotometry of supernovae shortly after discovery (Kirshner et al. 1973a,b, Kirshner and Kwan 1974, 1975, Kirshner, Arp, and Dunlop 1976) indicates that photospheric temperatures are moderately low (~10 000 K at maximum, cooling to 6 000 K in 30 days) and the atmospheres are very large (~3 x 10^{14} cm near maximum, expanding to ~10^{15} cm in 30 days) for both SN I and SN II. The rate at which the photosphere expands is roughly constant through the first month (-5000 km s^{-1} for SN II, higher for SN I). The large size of the supernova atmosphere, at least for SN II, agrees well with the computations for a massive star near the end of its life. Models for the supernova explosion which assume only the rapid deposit of 10^{50} - 10^{51} ergs in the core of a red supergiant can reproduce the observed luminosities, temperatures, and velocities rather well (Falk and Arnett 1977, Chevalier 1976). These adiabatic models do not require a continuing energy input from radioactive material or from a pulsar. Similar models for SN I (Lasher 1975) have had good success despite the fact that the atmospheres for SN I are probably hydrogen deficient. Wheeler (1978) has considered the possible classes of observed stars that have helium rich and highly extended atmospheres: the R Cor Bor stars are a possibility. The adiabatic models have shown that the efficient conversion of energy into luminosity in the optical region can take place for extended atmospheres, but that similar explosions in stars which have shed their envelopes will not produce the optical phenomenon we call a supernova.

(3) CHEMISTRY

For supernova remnants that are less than 1000 years old, the debris we see is principally from the supernova rather than from the interstellar medium. Recent results on Cas A (Kirshner and Chevalier 1977, Chevalier and Kirshner, 1978, Chevalier and Kirshner 1979) and on G 292.0 + 1.8 (Goss et al. 1979) in our galaxy, N 132D in the LMC (Lasker 1980), and the remnant in NGC 4449 (Balick and Heckman 1978, Kirshner and Blair 1980) show that supernovae do eject gas at high velocities with very unusual abundances. The ejected gas in each of these cases has no detectible hydrogen, and consists principally of oxygen. In the case of Cas A, some fast moving knots show pure oxygen while others show oxygen plus the products of burning oxygen: surfur, argon, and calcium. By matching the observed abundances with those in models for the last stages of stellar evolution (for example, Weaver, Zimmerman, and Woosley 1978), it seems likely that these remnants arise from the explosion of massive stars in the 10-30 $M_\odot$ range. Of course, we do not know whether the explosions produced the luminous optical event that we call supernovae. At least for the case of Cas A, it seems likely that the star shed its envelope before the explosion and that the resulting optical output was relatively small.

(4) CONCLUSION

All the available lines of evidence from statistics, from the state of the star at maximum light, and from the chemistry of the ejecta point to the origin of supernovae in massive and short-lived stars. The most controvertial point is the origin of SN I in elliptical galaxies, since the presence of supernovae that come from massive stars requires substantial present-day star formation in these systems.

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