Supernova Observations

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Abstract

A summary of the proliferaton of details in the observational picture of supernovae over the last decade is given. Hydrogen-poor Type Ib/c supernovae have been recognized to be "stripped" Type II supernovae, i.e. explosion of massive stars. The observational appearance is largely determined by the evolutionary history of the progenitor system. Other objects, where the emission is dominated by the conversion of kinetic energy from the explosion rather than the result of radioactive decays of freshly synthesized isotopes, are most likely products of supernovae in dense cirumstellar environments.

Explosions of white dwarfs are displaying slight differences in light curve shapes and spectral variations. Correlations between various signatures, like light curve decline rates, line strengths, and luminosity have been established, but might now work universally as first exceptions are being detected. More work is needed to connect the predictions of explosion models with the actual observations. In particular, the observational distinction between the two main explosion mechanisms, He-shell detonations and core C-burning, has to be explored.

The current status of supernovae as distance indicators is reviewed briefly and the application of the time dilation test for universal expansion as observed in SN 1995K outlined.

A Decade of Change

A decade ago the observational picture of supernovae (SNe) was simple and ordered. Two generally accepted classes could accommodate nearly all events and only only few peculiar objects were known (Woosley & Weaver 1986). The first signs of change were, however, already perceived with a new subtype proposed for hydrogen-poor supernovae (for the sequence of events see Harkness & Wheeler 1990).

The cross-dressing character of Type Ib/c supernovae was clearly recognized only after a few years with the detailed observations of SN 1993J (Wheeler & Filippenko 1996). Almost simultaenously the explosion of the "wrong" star in the "wrong" place (in the H-R diagram) has lead to an overhaul of the progenitor histories of these stellar explosions (Arnett et al. 1989, Woosley et al. 1994). Meanwhile there have been many hydrogen-displaying supernovae with peculiar line shapes and velocities which are clearly not reflecting the true explosion energies (SN 1986J: Rupen et al. 1987, Leibundgut et al. 1991; SN 1988Z: Stathakis & Sadler 1991, Turatto et al. 1993). Other long-held assumptions had to be abandoned. So are the explosions no longer homogeneous or spherically symmetric, nor is the emission only dominated by the cooling debris which emits photons emerging from the radioactive decay chains. Emission at very late phases (several years past maximum) has by now been detected from about a dozen supernovae (Fesen & Becker 1989, Long et al. 1992, Fesen & Matonick 1994, Leibundgut 1994).

These objects are not yet in a remnant phase, but change their luminosities on time scales of years (Long et al. 1992).

The old classification scheme (Harkness & Wheeler 1990) clearly has reached its limits now. With increasing information on individual events we are starting to probe the physics of each explosion and can determine the conditions in the supernova. Deviations from the norm can be described. The observations of the nearby SN 1987A and SN 1993J have proven particularly interesting in this respect. The polarimetry revealed the non-spherical nature (Trammel et al. 1995) as well as the line shapes at late times (Spyromilio & Leibundgut 1996). Its evolution from a close binary system seems inevitable (Woosley et al. 1993). A general link is proposed between explosions of stars which retain a significant fraction of their hydrogen envelope (Type II supernovae) and objects which have been stripped of almost all hydrogen (Type Ib/c supernovae). The subclassification of the last group has proven particularly difficult as it depends on small differences in their spectral appearance (Harkness & Wheeler 1990).

Type Ia supernovae have transformed from pure to modified "standard candles" (Phillips 1993, Hamuy et al. 1995, Riess et al. 1996). Several SNe Ia have been found to definitely deviate from the majority of the events. The light curve shape has emerged as a very useful discriminator (Suntzeff 1996). The addition of R and I filter light curves has complemented the already known peculiar behavior with two maxima in the infrared light curves (Elias et al. 1981). The second maximum changes in strength and time in a continuous way from the blue to the red (Suntzeff 1996).

The ordered nature of the events is maintained with some correlations between early and late decline rates (Phillips 1993, Hamuy et al. 1995, Vacca & Leibundgut 1996a), lines which act as temperature indicators (Nugent et al. 1995), and color and luminosity of the objects (Hamuy et al. 1995, Riess et al. 1996). However, first exceptions are already reported. The bright SN 1994D appears to violate most of the established correlations (Richmond et al. 1995, Patat et al. 1996).

The exact explosion process of SNe Ia is still debated with He-shell detonations of sub-Chandrasekhar mass white dwarfs as a new possibility (Woosley & Weaver 1994). These models are quite satisfying in regard to the statistics of progenitor systems, but may fail in the detailed nucleosynthesis as well as the observed light curves and spectra. Major progress could be achieved should we be able to observationally separate the possible explosion models. Candidates favored for He-shell detonators are faint, red SNe Ia like SN 1991bg (Filippenko et al. 1992, Leibundgut et al. 1993, Turatto et al. 1996). The difficulties are partially related to the problems in calculating theoretical light curves and spectra from the explosion models due to the highly complicated physics involved (Eastman 1996). Attempts to compare observed bolometric light curves with the models and develop simple comparison strategies, like the rise time to peak, are under way (Vacca & Leibundgut 1996b). Another unexpected development is the detection of a light echo towards SN 1991T (Schmidt et al. 1995). The light curve of this supernova flattened two years after explosion due to light scattered toward the observer by intervening clouds.

Despite the new variety among SNe Ia they remain a main contender for cosmological distance measurements. They have been used for the determination of the Hubble constant by several groups recently (Hamuy et al. 1995, Branch et al. 1996, Sandage et al. 1996, Riess et al. 1996). No concensus has yet emerged, but the discrepancies are slowly being clarified (Riess et al. 1996). Two independent groups attempt to measure the cosmic deceleration (Perlmutter et al. 1995, 1996, Schmidt et al. 1996, Leibundgut et al. 1996). While it is too early to measure q_0, important results have already been achieved. Time dilation in the light curve of SN 1995K, a SN Ia at $z=0.478$, is the most adequate interpretation of the observed photometry, a clear sign of expansion of the universe (Leibundgut et al. 1996). Light curves of other distant supernovae, likely SNe Ia at $0.3<z<0.5$, are also stretched according to the expectations of expanding universe models (Goldhaber et al. 1996). Currently, about a dozen spectroscopically classified SNe Ia at large distances (z>0.3) are known and with the addition of another 20 we should be in the position to accurately determine the deceleration.

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