CONFERENCE SUMMARY

From Twilight to Highlight: the Physics of Supernovae

ESO/MPA/MPE Summer Workshop 2002

(http://www.mpa-garching.mpg.de/~supnov/)

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This year's joint workshop between ESO, the Max-Planck-Institut für Astrophysik and the Max-Planck Institut für Extraterrestrische Physik, already the fifth in this series, was dedicated to the physics of supernovae. With active groups at all three institutions (and at both of ESO's scientific centres in Garching and Vitacura) this topic was ideal. Over 100 experts came to Garching during the last three days of July to discuss the progress made in the explosion physics, the current observational status, the astrophysical relation of supernovae and their environment, and the most energetic explosions known.

With increased attention to supernovae for their cosmological application and their possible connection to the Gamma-Ray Bursts (GRB) during the past few years these stellar explosions have entered into the limelight of the astronomical stage. However, our understanding of the underlying physics advances more slowly and its progress has to be evaluated regularly. It was the goal of this meeting to focus on the basics of the explosions and the current knowledge of these cosmic highlights.

The meeting was structured with reviews opening the sessions on the individual topics. The first day started with the evolution of stars towards the final core collapse or the ignition of a thermonuclear flame. The outcome of massive star evolution depends on the initial metallicity, which governs the stellar mass loss and hence the mass at the explosion, and during the early universe even very massive stars (up to 250 $M_{\odot}$) can explode as supernovae (Heger). Direct observational evidence of the progenitor stars of core-collapse supernovae is still hard to come by and, with the notable exceptions of SN 1987A and SN 1993J, only upper limits can be set on the progenitor luminosity and initial mass (Smartt). The finer details of the progenitor evolution for SN 1987A still have to be worked out. Almost everybody agrees that there must have been a binary system (Podsiadlowski). The binary may have fully merged shortly (10^4 years) before the explosion. The many constraints on the progenitors of thermonuclear supernovae (Type Ia Supernovae) and their evolution to explosion were presented in a coherent picture (Nomoto). This has also implications on the relative supernova rates as a function of look-back time, i.e. redshift. Nevertheless, there remain many open questions and the debate whether double-degenerate models (a binary consisting of two white dwarfs) or the single-degenerates (a white dwarf with a main sequence or giant star as companion) are the progenitor systems was continued at this conference. From the cosmic SN Ia rate the double-degenerate systems appear less favoured due to their long evolutionary time (Canal) and the recurrent novae, in particular in super-soft X-ray sources, appear more promising candidates (Starrfield). An especially attractive feature of the super-soft sources is that the measured white-dwarf masses are already very close to the Chandrasekhar limits.

A systematic survey of white dwarfs for radial velocity changes with UVES has so far yielded quite a high fraction of binary white dwarfs (16%). Among the best candidates are three objects with a combined mass very close to the Chandrasekhar limit and two of these will merge in about 4 Gyr (Napiwotzki). The search for the companion stars after they have lived through the violent explosion in their vicinity has so far not yielded positive detections (Ruiz-Lapuente). In particular, Tycho's supernova (SN 1572) and SN 1006 have been investigated. The physics of the core collapse in massive stars was beautifully introduced (Janka). There might be light at the end of the tunnel with the first multi-dimensional calculations yielding explosions when general relativity and new neutrino opacities are used in the models. The treatment of the neutrino transport is key in these models, a view also echoed by other experts (Burrows, Mezzacappa) but even more sophisticated models may be needed to confirm the first positive results. Gross asymmetries appear in some model calculations. The copious production of neutrinos in the core collapse might be observable with a suitable supernova in the Milky Way. Neutrino oscillations can be measured from these supernovae and will provide important diagnostics for neutrino physics and the neutrino masses (Sato). The models of thermonuclear supernovae have progressed tremendously during the past decade as well. 3-dimensional calculations of the turbulent nuclear flames in deflagration models appear now to solidly produce explosions and about the right masses of ^{56}Ni. With increasing resolution in the simulations more energy is released and explanations for regular SN Ia dynamics appear within reach even with pure deflagration, i.e. subsonic, explosions (Niemeyer). Should a transition to detonations occur then the explosion can be further strengthened (Garcia-Senz).

There is a bonanza of new observations being assembled on supernovae. Most of the second day of the workshop was dedicated to presentations of new data. The Berkeley group is not only currently finding most of the nearby supernovae, they are also assembling a large sample of light curves and spectra (Filippenko). Among the recent supernovae there are many peculiar ones and with SN 2002cx a truly strange SN Ia has been added to the zoo. The latest news on SN 1987A was presented in two presentations. The shock interaction with the inner ring has become quite apparent during the last few years in HST imaging (Kirschner). The light curve is dominated by the ring emission and extracting the fading ejecta requires HST imaging (Suntzeff). The supernova itself is fading now very slowly. The first tentative spectral identification of a supernova (SN 2001ek) in a Gamma-Ray Burst afterglow (GRB 011121) triggered some discussion on data quality and wishes for longer integration times (Kirschner). Densely sampled light curves in UBVRI and the infrared JHK bands for several nearby supernovae are now becoming available. With these excellent observations the construction of bolometric light curves becomes a lot easier and the global properties of SNe Ia can be assessed (Suntzeff). Core-collapse supernovae with very weak explosions are observed more often and their general appearance can be investigated (Turatto, Pastorello). The ejecta mass of the weak explosions is still debated, but higher masses appear to be favoured (Zampieri). For these weak objects, it might be possible to directly see emission from the infall of matter into a black hole at very late phases.

With large telescopes, including the VLT, some supernovae can now be followed for over a decade enabling one to look deep into the ejecta and explore the heating mechanisms working in these cinders (Turatto). An interesting transition object between the subclasses Ib and Ic has been observed in a Large Programme at the VLT (Hamuy). The early adiabatic cooling from the shock breakout and the exquisite IR spectroscopy firmly establish the core-collapse nature of this object. The infrared wavelength regime will draw much more attention in the near future. It offers the possibility to observe supernovae with much less influence from host galaxy absorption. The possibility of an H-band Hubble diagram of SNe Ia would make this fundamental measurement less dependent on assumptions about absorption in the host galaxies (Phillips). At the same time, many new SNe Ia show light curves and spectral evolutions that can not be fit into the one-parameter relations used in the past. The infrared also provides access to phenomena which are not easily observable in the optical. The core-collapse supernova SN 1998S is an intriguing case where the careful optical and infrared monitoring not only revealed very strong interaction with circumstellar material, i.e. the remnant of the wind of the progenitor star, but also an infrared excess (Meikle). Dust formation in the cool shell between forward and reverse shock has been deduced from these observations.

To bridge the gap from explosion models to the observations the radiation transport has to be calculated. The comparison of the latest explosion models from the group at the MPA with observed light curves are very encouraging (Blinnikov). Indeed there appears to be enough energy in the deflagration models to explain the ejecta velocity of the Tycho supernova remnant. During a poster session the 28 posters on a wide range of topics were discussed. Supernova searches and recent observations of specific objects were presented. The latest ideas and details on modelling the explosions were displayed as well as plans for future projects.

The last day was devoted to the interactions between other astronomical fields and supernovae. Not all supernovae explode in isolation. Some of them strongly interact with their close environment. The radio and X-ray emission are the most direct tracers of this circumstellar interaction of the supernova shock, but optical spectroscopy can reveal the emission sites through line shapes as well (Chevalier). Most regular SNe IIP show very little sign of interaction consistent with progenitor masses in the range of 10 to 20 $M_\odot$. Many other objects, especially stripped core-collapse supernovae (IIL, Ib/c), are enshrouded in a dense environment, which most likely resulted from the evolution in a close binary system.

To date only 15 supernovae have been observed in X-rays (Aschenbach). All of them are core-collapse supernovae interacting with their circumstellar material. Recently the first X-ray spectra have been obtained showing high ionization lines of oxygen through iron. The flux from SN 1987A is increasing as the shock is interacting inside the ring with dense, ionized material. SNe Ia, on the other hand, are postulated to explode in a rarefied environment and no interaction is expected. However, in some progenitor models the presence of hydrogen or helium has to be expected. Finding the traces of such material has been the goal of a UVES programme (Lundqvist). So far, only upper limits for the mass loss can be derived from the absence of any detection of hydrogen or helium lines. On a grander scale, the supernova light can scatter off dust grains between the explosion and the observer. There are now two SNe Ia and two core-collapse SNe (SN 1987A and SN 1993J) with observed light echos (Patat). Since supernovae are the main producers of heavy elements, they are of special interest for models of the chemical evolution of the Galaxy (Thielemann).

The relative contributions of thermonuclear and core-collapse supernovae should sum up to the abundances measured in the Sun. The dependences on various parameters in the explosions (density, temperature, and metallicity) are still not fully explored. It has been claimed recently that the chemical composition of the most metal-poor stars could be dominated by a single supernova. Hence, these most pristine stars are of particular interest for the explosion models. The comparison of the evolution of individual elements in stars yields hints about the contribution of different supernova types (Primas). Some of these stars may be the first ones formed in the galaxy, the putative Population III. But also celestial objects picked up from the ground can provide information on supernova enrichment. Inclusions in meteorites give hints on the composition of the early solar system and material ejected from nearby supernovae (Ott).

A discussion on the nomenclature of the most energetic explosions was the guiding theme of the following presentations. The very first massive stars should explode in truly gigantic explosions even on the supernova scale. The chemical composition of the metal-poor stars might be dominated by these explosions of the first generation of stars (Limongi). The observed abundances cannot be matched with the current models, but progress could be reported. The nucleosynthesis can also be altered, if the explosion is asymmetric as the conditions for the burning are not isotropic any longer (Maeda). Direct detection of the γ radiation from the radioactive decays would constraint the explosion models considerably. With the past satellites this has been very difficult but the situation will improve after the launch of *INTEGRAL* this fall (Diehl). Decay lines from ^{56}Ni and ^{57}Co were observed from SN 1987A and a tentative detection of the ^{56}Co decay in the SN Ia SN 1991T was reported. Other decays have been observed in supernova remnants (^{44}Ti in Cas A) and distributed throughout the Galaxy (^{26}Al). The connection of Gamma-Ray Bursts and supernovae may be intimate, it certainly is intricate (Woosley). With sufficient angular momentum the formation of a black hole can trigger the formation of a disc formed of nucleons, which can reverse the infall along the poles into a strong jet explosion. Depending on the viewing angle the observer will see a GRB, an intermediate object like GRB 980425/SN 1998bw or an unusual supernova. Depending on the conditions outside the disc the nucleons can form nuclei up to Ni and hence trigger a supernova (MacFadyen). The disc itself could be the site of an reprocess. The problem of this scenario is to produce stellar cores with sufficient angular momentum for these models. A possibility is to have either a merger event or mass accretion onto a massive star (Joss). The observational parameters of some of these energetic explosions can vary from object to object (Mazzali). A range of explosion energies and masses has been observed until now. The spectral signatures of wide, high-velocity lines of what otherwise might appear as a SN Ic are quite obvious.

Despite an intense programme there was plenty of time for discussions. The workshop was opened with a buffet dinner and a speech by the Mayor of Garching in the town hall. The first day ended with a relaxed 'Beer and Bretzen' party outside the MPA. The conference dinner took place at a typical Bavarian *Biergarten* outside Munich during a wonderful summer evening. All occasions to informally catch up on the latest news and developments.

The proceedings of this conference will appear in the ESO Astrophysics Symposia Series published by Springer Verlag.