Supernova shells

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W. Kundt, Ed. *Supernova Shells and Their Birth Events: Proceedings, Bad Honnef, FRG, 1988.* Springer-Verlag, Berlin; Heidelberg; New York; London; Paris; Tokyo, 1988. pp. 253 (Lecture Notes in Physics. V. 316)

The book is a collection of materials of a workshop that took place on 7–11 March 1988 in the Physics Center at Bad Honnef, FRG. The conference examined the present, in many aspects contradictory, state of knowledge concerning the origin, evolution and morphology of expanding supernova shells (SNS). Progress, on the one hand, in the methods of observing, and, on the other hand, in the modeling of processes of expansion of and radiation from SNS, forces as the editor of the book, and one of the initiators of the workshop, W. Kundt notes in the introduction, a "rejuvenation" of this branch of astrophysics which already has an established tradition. The explosion of SN 1987A in the Large Magellanic Cloud has greatly increased interest in the problem of SNS and has exerted an undoubted influence on the workshop.

The materials of the collected papers are grouped into 4 chapters: 1. Supernova shells, General; 2. Supernova shells, Special objects; 3. Supernova explosions; 4. Supershells and high-energy particles. Chapter 1 begins with a paper by W. Kundt in which the author advances a hypothesis concerning fragmentation of a supernova shell at the earliest stages of the explosion ("fragmentation bomb"). As observational foundations for this hypothesis the author advances: 1) peculiarities in the morphology of some SNS, in particular of the Crab nebula and Cas A ("chimneys"); 2) barrel-shaped mass distribution in SNS; 3) presence in many SNS of ejecta beyond the boundaries of the shell (at distances up to 3 radii of the shell); 4) presence in some SNS of ropelike condensations; 5) the problem of the discrepancy between the expected maximum age of the SNS and SNS statistics; 6) a significant excess of the duration of the free expansion of some SNS over the expected duration within the framework of the Sedov-Taylor approach. In the case if the hypothesis concerning the fragmentation of the SNS is valid, then the approach to the modeling of the dynamics of expansion of SNS and the estimates of the energy of the supernova expanded on the formation of the SNS must be reevaluated (in the author's opinion the kinetic energy of the fragments can exceed 10^{51} erg). The reviewer would add that the supposition concerning the large-scale inhomogeneity of the shell of SN 1987A has been advanced by R. A. Syunyaev to explain the unusually early observation of x rays from SN 1987A. The fragmentary nature of the SNS can also lead to an earlier observation of a pulsar–the remnant of SN 1987A if it exists.

G. Srinivasan and D. Bhattacharya report results of calculations of the evolution of the luminosity of SNS consisting of a plerion and a shell proper. The luminosity of the plerion was determined by the "pumping" of energy from the pulsar, the luminosity of the shell component was determined by the interaction in the interstellar medium and processes in the shell itself. The amount of mass ejected in the explosion of the supernova, the initial velocity of the ejecta, the intensity of the magnetic field and the period of the pulsar, and also the density of the interstellar medium were specified as free parameters. The authors' conclusions reduced to the statement that the values of the initial parameters determine the evolution of the SNS in a significant manner: in the case of weak explosions (the energy liberation in the SNS less then 10^{50} erg) young SNS manifest themselves as bright plerions, gradually transforming into SNS of the shell type. In the case of strong explosions (energy liberation of the order of 10^{51} erg) in remnants with rapidly (period of the order of 5 ms) and slowly (period greater than 100 ms) rotating pulsars evolution also proceeds from predominantly plerion to shell type of SNS (as an example MSH 15–52 is examined). However in Crab-like remnants (the period of the pulsar is of the order of 20 ms, "strong" explosion, magnetic field $\sim 10^{12}$ G) the luminosity of the plerion was always dominate. In the authors' opinion due to the absence of plerions in the majority of the SNS it follows that the majority of neutron stars is born with large rotation periods.

The statistics of the SNS is discussed in the papers by D. A. Green and Sidney van den Berg. Van den Berg demonstrates the close correlation between the distributions of the galactic radio-SNS of CO-emission, and also of emission in the infrared and the gamma ranges and concludes that the distribution of the SNS is closely tied to the distribution of the interstellar gas. Therefore the estimate of the frequency of flare-ups of supernovae in the galaxy based on the statistics of the SNS may be too low as a result of flare-ups outside the galactic plane which do not produce noticeable SNS. D. A. Green discusses the effects of observational selection associated not only with restricted sensitivity, but also with finite angular resolution of the equipment. Due to these effects one observes neither weak SNS nor bright ones but with small angular dimensions, and this also may reduce frequency of flare-ups of supernova in the galaxy. R. G. Strom proposes an approach to the determination of relative distances to remnants of historical supernovae of the 1 type (SN1), based on using the Sedov-Taylor relation between the remnant radius r, the explosion energy E, the density of the medium N and the expansion time t: $r \propto (E/N)^{1/5} t^{2/5}$. W. Reich and E. Fürst report data on the statistics of recently discovered galactic SNR. The addition of the new data does not significantly change the spatial distribution of the galactic SNR. In another paper presented at this workshop E. Fürst and W. Reich provide a review of data on the variation of spectral indices in the radio range, devoting particular attention to the SNR S147. In the opinion of the authors the radio emission from S147 indicates the existence of two components: a small-scale one tied to the optical filaments, and a

large-scale one, which is interpreted as emission from a gas-.Different approaches to the interpretation of a break in the spectrum in the region of 1GHz are discussed.

Different aspects of the dynamics and mechanisms of emission from SNR are examined in the papers by W. Brinkman, S. A. E. G. Falle and J. R. Giddings, and also by D. E. Innes based on computer simulation. As all these authors note the available knowledge concerning SNR are insufficient for adequate modeling. W. Brinkman emphasizes the necessity of a significant improvement in the spatial resolution of x-ray detectors for obtaining physically significant data on the nature, chemical composition and mechanisms of radiation from remnants of both SN1 and SN2. The importance of taking into account the effects of nonequilibrium ionization is also demonstrated. Falle and Giddings modeled the interaction of a shock wave with the inhomogeneities of the interstellar medium. On the basis of the results obtained the authors confirm the hypothesis of the origin of the filamentary structure of the Cygnus Loop as a result of diffraction and scattering of the primary shock wave by the large-scale (of the order of 1 pc) inhomogeneities. D. E. Innes comes to the conclusion concerning the similarity of radiation from a nonadiabatic radiatively unstable shock wave and radiation from a "standard" stable wave with a lower velocity.

The next chapter examines individual objects. R. Bandiera discusses the hypothesis advanced by him earlier (in 1987) that Kepler's supernova belongs to type 1b and has as a precursor a star of the Wolf–Rayet type in a binary system with a neutron star. The result of an explosion of the supernova can be the birth of a binary system of neutron stars. R. G. Strom examines the peculiar remnant CTB80, which exhibits the presence of almost all the components of a SNR. D. K. Milne *et al.* discuss data from observations at a frequency of 843 MHz of the remnants of G316.3–0.0 and G332.4 + 0.1. Both remnants have a shell structure with ejecta, which can be either the result of penetration of plasma into the cavities of the interstellar medium, or a toroidal magnetoplasma structure. R. G. Arendt, E. Dwek and R. Petre present data on observations in the infrared range of the object Puppis A and estimate the parameters of this remnant. D. A. Green reports observations with high angular resolution (3″) in the radio range of SNR G11.2–0.3 which show that the shell has ejected and has a similarity to Cas A.

M. de Muizon *et al.* discuss new data in the radio range concerning a peculiar galactic object G70.7 + 1.2 which in the opinion of the authors is a radio shell. W. Reich, N. Junkes and E. Fürst report the discovery of a compact molecular cloud in the direction of G70.68 + 1.20. The density of the cloud exceeds 100 cm^{-3}, the diameter is approximately 0.55 pc and it is at a distance of approximately 5.5 kpc. The authors think that there are weighty arguments for associating this object with G70.68 + 1.20. The same authors report discovery of 4 new galactic SNR in the radio range at a wave of 11 cm. It is also found that approximately 50% of the known remnants have in this frequency range a high degree of polarization. H. Greidanus and R. G. Strom report data on observations of the $7' \times 7'$ field in the Swan Loop in the H_α and OIII lines. The angular resolution amounted to 7″. The observations were made in order to determine the kinematic characteristics of the optical components. The authors interpreted the observations in the OIII line as an indication of the existence of a thin gas "sheet". J. J. Claas reports results of processing the data of the observations of the SNR G292.0 + 1.8 in the x-ray range of 0.5–10 keV. In order to describe these data within the framework of the model of equilibrium ionization it is necessary to introduce two radiating components with different temperatures of 0.5 and 2.0 keV, and this may be an indication of the nonequilibrium nature of the ionization process. The author notes that the attempt to explain the existence of low-temperature and high-temperature components by introducing the model with a reverse shock wave (one of the consequences of the approach on the basis of the Sedov-Taylor equations) leads to a considerably higher temperature difference.

The review by J. M. Lattimer introduces a group of articles devoted to supernovae in particular SN 1987A. It examines the dynamics of the collapse of the core of massive stars at the end of their thermonuclear evolution and the accompanying effects of the collapse. In particular, special attention is devoted to neutrino radiation and the attempt of a theoretical explanation of events recorded by underground neutrino installations at the time of the explosion of SN 1987A. On the whole the review is of interest because of its condensed presentation of the modern theory of gravitational collapse, the problem of the ejection of a shell of the star and neutrino radiation. It is noted that until now no one succeeded in discovery the mechanisms of the transfer into the shell and the mantle of the star of energy sufficient for their ejection. The hydrodynamic shock wave, arising when the compression of the core of the star ceases, spends its energy on its way to the surface on the dissociation of iron nuclei, while the neutrino pressure has little effect due to the capture and a comparatively slow (~ 10 s) diffusion of the neutrinos from the proto-neutron star. It is also noted that the dynamics of neutrino luminosity is determined primarily by the processes of diffusion of neutrinos formed at the initial state of the collapse, and also by the cooling of the neutron star. Comparing the theoretical shape of the curve of neutrino luminosity with the distribution in time of pulses in events recorded on underground Cherenkov detectors Kamiokande II and IMB at $\sim$7:L35 UT 23 February 1987, the author concludes that these detectors recorded neutrinos from the collapse which led to the flare-up of SN 1987A. We note that the experimental pattern of events in underground detectors at the time of the flare-up of SN 1987A is much more complex than is described in the above review (cf., for example, Ref. 1), and does not give unique indication that neutrinos were detected. Among the deficiencies of the above review one can also include the total lack of familiarity of the author with the work of Soviet theoreticians. Thus, the concept of the formation of a hot neutron star cooled by neutrino emission was proposed not in the paper by Burrows, Mazurek and Lattimer in 1981 as is indicated in the above review, but considerably earlier in a number of papers by the group of V. S. Imshennik and D. K. Nadezhin published in the 1970's (cf., for example, Ref. 2). At the same time the curve of neutrino luminosity was obtained, and also the problem of ejection of the shell of a SN was formulated.

W. Kundt in his second paper of the present collection of articles examines the concept of a "magnetic spring" which transmits into the shell of the star the energy of a rapidly rotating newly-born neutron star which leads to the

explosion of the SN. He notes that the shell in this process expands not as a homogeneous plasma, but fragments into dense clumps. An explanation is offered for the exponential falling-off of the luminosity curve of a SN as a result of the diffusion of photons from these clumps. We note that this approach can completely change the picture of the increase in luminosity of a SN at the very earliest of the explosion compared with the hydrodynamic calculations.

S. Van den Berg in examining the spectra and the statistics and spatial distribution of supernovae of types 1b and 2 comes to the conclusion that like SN1b stars explode that have a mass greater than 15 solar masses on the Main Sequence, while the progenitors of SN2 have at the stage of the Main Sequence masses from 8 to 15 solar masses. At the same time *N.* Panagia and V. G. Laidler provide arguments opposing this. In their opinion a flare-up of the Sn1b type is brought about by the explosion of a star of moderate mass of the order of 7 solar masses which belongs to a binary system. In our opinion this discussion shows once again that in spite of the obvious progress of theory no final consensus has yet been reached in understanding the nature of SN of different types.

N. Panagia presents a review of the results of observations of SN 1987A in the ultraviolet range with the aid of the IUE satellite. The observations lead to the following conclusions: 1) the radius of the exploded star is relatively not very great, several tens of solar radii; 2) the blue super giant Sk-69°202 of the B3I class is the only candidate to be regarded as a presupernova; 3) the presence of narrow emission lines NV 1240 Å, NIV 1483 Å, HeII 1640 Å, OIII 1663 Å, NIII 1750 Å, CIII 1909 Å, that appeared after May 1987, and also the low velocity of expansion of the emitting gas associated with these lines (10–30 km/s) lead to the suggestion that Sk69°202 has passed through the stage of a red supergiant, and the observed components are slowly expanding external layers ejected by the red supergiant in the form of a stellar wind. If the latter supposition is true, then the collision of the external layers of the shell of SN 1987A expanding with a speed of up to 30,000 km/s with previously ejected matter will lead to sharp increase in the intensity of the ultraviolet radiation during the next 10 years.

It is well known that x rays from SN 1987A appeared unexpectedly rapidly. Already after 4 months after the flare-up they were detected by the satellite Ginga and the Kvant module of the Mir station. The spectrum of the radiation disappears under the photoelectric barrier (~ 10 keV) and its short-period variations are noticeable. In order to explain the peculiarities of x rays from SN 1987A, R. Bandiera, F. Pacini and M. Salvati propose a model in which the central pulsar with the period of approximately 20 ms "feeds" the plerion partially concealed by the external shell. In this case the external shell consists of chaotically moving fragments with dimensions comparable at the early stages of expansion with the diameter of the shell. According to this model the observed x-ray intensity will increase with time approximately at $t^{1/2}$. Comparing the spectra obtained on the Ginga satellite in September 1987 and January 1988 the authors conclude that the proposed model agrees qualitatively with observations.

N. Bartel provides a review of data obtained with the aid of a very long base radiointerferometer (VLBI), for 6 young SNR: SR 1987A (the age at the time of observation of approximately 0.01 year), SN 1980K (2.5 years), SN 1979C (3.7 years), SN 1986J (age from 3 to 12 years), SNR 419 + 58 (age from 22 to 50 years) in the M82 galaxy and SN$\sim$1850 (age approximately from 60 to 200 years) in NGC4449. Radiointerferometry with intercontinental bases is a comparatively young branch of radio astronomy. Among the achievements of VLBI the author includes: obtaining the image of SNR419 + 58 in another galaxy at a distance of 3.3 Mpc (angular resolution of 0".34), determination of the velocity of angular expansion and of limits on its change for SN 1979C in the M100 galaxy from the galactic cluster in the Virgo constellation; the measurement of the dimensions of the radio shell of SN 1987A, and also the measurement of the distance to the cluster in Virgo and the value of the Hubble constant (on the basis of measuring the distance to M100 the value of $H_0 = 60 \pm 20$ (km/s)/Mpc) was obtained.

P. L. Biermann discusses the data from observations of compact radio sources in the M82 galaxy and concludes that they are old or very young remnants of supernovae emitting in the radio range. The distribution of sources according to the spectral indices α has two clearly expressed maxima in the vicinity of the values $\alpha \simeq -0.5$ and $\alpha \simeq -1.0$. The nature of such a distribution so far is not clear.

J. Spicker and J. V. Feitzinger examine in their paper the supershells in the Large Magellanic Cloud. There is a problem of a discrepancy between observations and expected dimensions and velocities of expansion of supershells. The authors suppose that a realistic scenario of the expansion of SNS at the very latest stages of their evolution must take into account the inhomogeneity of the interstellar medium and the possibility that in the process of the interaction of the SNS with the interstellar medium remnants of clouds and of the intercloud medium that existed prior to the passage of the shock wave remain within the shell. SNS inject energy into the interstellar medium on all scales. L. A. Zank and H. J. Volk carry out a calculation of the generation of cosmic rays at the late stages of the evolution of SNS and conclude that the SNS remain the most probable source of cosmic rays with energies up to 10^{14} eV/nucleon.

In conclusion one may regretfully note the total absence of Soviet investigators at the workshop in Bad Honnef in spite of the active work carried out in our country in the areas of the physics of SN and SNS discussed above. It is difficult to conjecture what was the cause (or causes) of this situation, but a more active participation by the Soviet side of the workshop would have been, without any doubt, very useful.

[1]V. L. Dadykin, G. T. Zatsepin, and O. G. Ryazhskaya, Usp. Fiz. Nauk **158**, 139 (1989) [Sov. Phys. Usp. **32**, 459 (1989)].
[2]K. D. Nadezhin, Neutrino emission during the formation of a hot neutron star and the problem of ejection of a shell. (In Russian). Preprint Inst. Appl. Math. Acad. Sci. USSR No. 26, Moscow, 1976; Astrophys. Space Sci. **53**, 131 (1978).