early supergiants by its large amplitude (up to 0.65 mag in U, 0.50 mag in B, and 0.35 mag in V) and its very long time scale (440 days). Since 1985 the star was also observed repeatedly in the infrared by ESO staff astronomer Thibaut Le Bertre. The variability is seen until 3.4 micron, where it amounts to 0.03 mag. Light curves are in phase over the whole spectral range observed. The amplitude roughly follows a $1/\lambda$ law.

It seems established that the variability is due to intrinsic variations of the underlying star, but what is going on is not clear at all. The period is much too long for radial pulsation, and colour variations are very large for nonradial pulsation. During the brightening of the star in early 1987 a series of high-resolution observations of the $H\alpha$-profile was obtained. There is a correlation between the photometric and spectral variability. The Balmer lines $H\alpha$ and $H\beta$ show (variable) emission components with central absorptions, and are best interpreted in terms of a decelerated outflow of mass from the star.

HR 4049 thus being a mass-losing variable star, it may indeed be that the dust envelope which is observed was not expelled during the AGB, but is of more recent origin. That could explain the high temperature of the dust and may be compatible with the faintness of the envelope relative to what is seen in candidate-proto-planetaries. This possibility raises the interesting questions whether other post-AGB stars also undergo a HR 4049-like phase, and, if so, how this phase does contribute to the planetary nebula.

More about the Dust of HR 4049

Unraveling the peculiarities of HR 4049 will need more observational efforts. These efforts may be rewarding in a broader scope than originally aimed at. As an example, it turns out that HR 4049 is a very interesting laboratory for the study of the interstellar medium. In general, interstellar dust contains various components which are not easily deconvolved. On the other hand, the composition of HR 4049 is so peculiar, that its dust may be expected to be peculiar as well. Indeed, although the UV deficiency of the object is extremely severe, there is no trace of the 2200 Å feature which is normally prominent in interstellar dust. On the other hand, the dust features at 7.4, 8.6, and 11.6 micron are clearly seen in the IRAS low-resolution spectrum. These last features have recently been attributed to the so-called "polycyclic aromatic hydrocarbons" or PAH's. The presence of PAH's in the dust of HR 4049 is not surprising, since hydrogen and carbon are so prominent; in fact the dust may be remarkably devoided of impurities. It is interesting to point out that the PAH's do not produce a significant 2200 Å absorption feature in the UV energy distribution of HR 4049. This supports the idea that PAH's are not responsible for the interstellar 2200 Å feature.

A Quest for Similar Objects

When an astronomer has encountered a strange object, he studies it, but also searches for other similar ones. If he is lucky enough and succeeds in finding a second one, he defines a class. Very soon, he has a class and some exceptions. That was also our experience. We think that it is probable that HR 4049 is related to some other supergiants with infrared excesses. Most of these stars are variable, many of them are high-latitude objects, some of them are metal-deficient. One of the most interesting stars in our sample may be the high-latitude ($b = 56°$) faint ($m_v = 8.8$) early-A supergiant HD 213985 (Waelkens et al., 1987). This star has an energy distribution not unlike that of HR 4049 and shows similar photometric variations; however, HD 213985 does not seem to present obvious spectral peculiarities. In fact, the more similar stars we find, the more pronounced does appear the peculiarity of HR 4049. So we found a class, but the exception is the very star we started with.

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Supernova 1987A

A Summary of the ESO Workshop held from 6–8 July 1987

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This has been a really exciting meeting! Not only have we heard many new results, but it has also provided a fine example of how science should be done. In particular we had vigorous interplay between theory and observation, contributions from a variety of wavelength regions and intense international collaboration.

In his introductory paper West showed that astrometry of SN 1987A places this object within $\Delta\alpha.\cos\delta = 0\farcs00 \pm 0\farcs04$ and $\Delta\delta = -0\farcs04 \pm 0\farcs05$ of the star Sk −69°202. This close positional agreement, plus the disappearance of Sk −69°202 in recent IUE spectra (Gilmozzi, Kirshner) shows beyond reasonable doubt that the B3I star Sk −69°202 was the progenitor of SN 1987A.

Sk −69°202 (star 1) has close companions (White and Malin) with V = 15.3, d = 2″65 (star 2) and V = 15.7, d = 1″4 (star 3). The a priori joint probability that Sk −69°202 should have two such close companions is $\sim 10^{-5}$ i.e. it is virtually certain that Sk −69°202 was a member of a physical multiple system. Since members of such a system are coeval, the progenitor of SN 1987A must have had a larger mass than the relatively unevolved star number 2. Assuming this star to be a main sequence object its magnitude $M_V = -3.6$ places a lower limit of $\sim 10\ M_\odot$ on the main sequence mass of the supernova.

A pre-outburst objective prism spectrum of Sk −69°202 (Wamsteker et al.) shows that NII λ3995 was significantly stronger in the supernova progenitor than in the B3Ia star Sk −67°78. Furthermore Kudritzky reported finding that Sk −65°21 and Sk −68°41 have helium abundances (by number) y = 0.35 ± 0.05 and y = 0.23 ± 0.05, respectively. This high helium abundance shows that at least some LMC blue supergiants are highly evolved post red giant objects. This conclusion is greatly strengthened by Cassatella's recent IUE spectra of SN 1987A which show that [N/C] ~50 to

80 and [N/O] ~ 2. This indicates that C has been converted almost entirely into N. A similar result had previously been found in the type II-L supernova 1979C.

The following is a summary of some of the photometric and spectroscopic properties of the supernova progenitor obtained by various Workshop participants: The star Sk −69°202 had V = 12.33 (after the contribution of stars 2 and 3 has been removed). From inspection of plates in the Harvard plate files Hazen finds no evidence that the SN progenitor exhibited significant variability during this century. From UBV photometry Sk −69°202 is found to have had E(B-V) = 0.17 ± 0.02. Objective prism spectra of the SN progenitor show no evidence for Hα emission. Finally IRAS scans of this part of the LMC do not show a signal at the position of the supernova indicating that there was no bright dust-shrouded object present at the position of the supernova. Polarization observations reported by Cannon, Menzies and Schwarz exhibit a constant foreground polarization of ~0.5% on which variations of up to ~1% are superimposed. This result suggests some patchyness in the expanding shell. Nevertheless, high-speed photometry by Helt shows no evidence for random brightness variations $\gtrsim 0.005$ mag on timescales of minutes to hours.

The most peculiar feature of SN 1987A remains its light curve. The supernova luminosity increased slowly for 3 months before finally reaching maximum between 1987 May 20 and 25. No other supernova has ever been observed to have a light curve quite like that of SN 1987A. The most likely explanation for this peculiar behaviour and for the low luminosity [M_V(max) = −14.9] of SN 1987A is that an unusually large fraction of its energy went into expansion of its atmosphere because the precursor was a blue supergiant at the time of core collapse. The idea that a supernova with a low-density envelope (i.e. a red supergiant) will emit more optical radiation than one with a denser (blue supergiant) atmosphere was, I believe, first proposed by Virginia Trimble. A possible problem with this view is that one might expect late-time ($T \gtrsim 100$ days) evolution of SN 1987A to be similar to that of other SN II. This does not appear to be the case since SN 1987A has B-V = 1.7, compared to $0.7 \lesssim -V \lesssim 0.9$ for the 4 other supernovae of type II that have been well observed at T ~ 100 days.

Cassatella and Kirshner find that narrow emission lines, which may be due to excitation of material at a distance of $\sim 1 \times 10^{18}$ cm, began to develop in late May. Moneti showed that recent observations over the range $1 < \lambda < 20\ \mu$ can be represented by the sum of two black bodies having temperatures $T_{BB} \approx 1200$°K and $T_{eff} \approx 5500$°K. The IR luminosity of the supernova is presently increasing linearly at a rate of $\sim 1\ L_{\odot}$ per second! It is not yet clear whether the IR excess in the spectrum of SN 1987A is due to free-free emission or to a dust echo from material at $\sim 1 \times 10^{18}$ cm from the supernova. Radio observations (Manchester) show that SN 1987A is not embedded in a dense circumstellar shell. Presumably the material at $R \sim 1 \times 10^{18}$ cm will become a powerful source of radio radiation ~30 years from now when it is overrun by the shock wave from the supernova.

Van den Bergh used the frequency of supernovae discovered by Evans in Shapley-Ames galaxies to estimate a supernova frequency of approximately one per 500 years in the LMC. From N(novae)/N(SNIa) = $(4 \pm 2) \times 10^3$ and Graham's estimate of 2 to 3 novae per year in the LMC van den Bergh obtains an estimated SNIa rate of 0.6 per thousand years in the Large Cloud.

Speckle observations by Meikle and by Chalabaev indicate that a bright "mystery spot" is associated with SN 1987A. According to Peter Meikle this unresolved source is invisible in U and B, marginally visible (Δm ~4 mag) at 5876 Å and clearly seen (Δm ~3 mag) at 6585 Å. The separation between the mystery spot and the supernova may have increased from 58 to 74 m arcsec during the period of observation. Some form of energy storage would appear to be required to account for the high luminosity of the spot. Alternatively kinetic energy could have been fed to the spot directly via a "jet". Such a jet might be similar to the sulfur jet seen in Cassiopeia A (van den Bergh and Kamper). It would be interesting to know if the compact H II region that Djorgovski appears to have found 1.″8 from the supernova is related to the mystery spot phenomenon or whether it represents an object related to the nitrogen-rich knots (Walborn) that are found to surround the supernova-like variable η Carinae. Pacini pointed out that a jet may develop when a plasma cavity surrounding a pulsar at the centre of a supernova develops a leak. Such a jet may break out some time before the pulsar itself becomes visible from Earth.

Perhaps the most exciting question discussed at the workshop was why SN 1987A was so different from any other supernova that has been observed to date. Part of the reason for such differences is, no doubt, that the progenitor of this object was a blue supergiant rather than a red supergiant. Maeder, Truran and Renzini all emphasized the fact that considerable "fine tuning" of models is required to produce core collapse in a blue supergiant. Parameters that can be adjusted are $\dot{m}$ and/or Z, m(ZAMS), V(rotation) and the amount of convective overshoot.

Reports on observations of neutrinos produced during core collapse represented one of the highlights of the Workshop. The reality of the Mt. Blanc neutrino event was the subject of lively debate. A closely related question is whether the time delay between formation of a neutron star, and its subsequent collapse to a black hole, amounts to hours or microseconds!

Branch showed that rather crude synthetic supernova spectra are able to reproduce the main features of the observations quite well. In particular he finds that the λ 6050 feature in SN 1987A can be reproduced without having to appeal to a greatly enhanced Ba II abundance. From an application of the Baade-Wesselink method to SN 1987A Branch obtains a distance of 55 ± 5 kpc, which is quite similar to the canonical LMC distance of 50 kpc.

Because of its enormous luminosity SN 1987A represents an ideal probe of the interstellar medium allowing very high dispersion spectroscopy. (After 1987 February 28 the UV brightness of the supernova became too faint to use that part of the spectrum for interstellar line studies). Andreani, de Boer and Grewing reported observations of between 24 and 40 distinct velocity components in their interstellar line spectra. These lines appear to fall into 4 distinct groups: (1) Clouds with $V \sim 0$ km s^{-1} are clearly of Galactic origin. (2) Clouds with $50 < V < 150$ km s^{-1} are located in the Galactic halo (or in a bridge between the Galaxy and the LMC). In these clouds the Na I/Ca II intensity ratios are low i.e. calcium is less depleted in them than it is in Galactic and LMC clouds. (3) Material with $V > 150$ km s^{-1} is clearly associated with the LMC. (4) A feature with V = 220 km s^{-1} is believed to represent a shell surrounding Sk −69°202.

An EUV pulse is expected to develop when the shock generated by core collapse reaches the surface of a SN progenitor. The total energy in such a pulse, which is expected to have $1 \times 10^5 < T < 1 \times 10^6$ °K, will be $\sim 10^{48}$ erg and the peak luminosity might reach $\sim 10^{46}$ erg sec^{-1}. Such an EUV pulse will generate electrons in the upper atmosphere of the Earth. Ögelman made the interesting suggestion that such a pulse from SN 1987A might be revealed by an increase in the night-time conductivity of the E layer.