DISCUSSION AFTER PAPER BY MASSEVITCH

Massevitch (in answer to comment by Chiosi): There are some difficulties in explaining the observed effective temperature range for blue supergiants in the case of both stability criteria. For the Ledoux criterion, an assumption of mass loss in the red supergiant region allows us to extend the interval of T_e sufficiently to reach an agreement with observations. On the other side, there are some difficulties in obtaining models with $\log T_e = 4.3$ and $M_{Bol} = -9$ if the Schwarzschild criterion is used. Thus effective temperatures do not provide a possibility to make a definite choice between the two criteria.

Schwarzschild: Mr Chairman, since the afternoon is quite advanced would it be proper to turn to some quite speculative points? I would very much like to ask Dr Paczyński whether he thinks that in the envelopes of massive supergiants instabilities exist which lead to a non-explosive major mass ejection, as seems to be the case for the less massive supergiants. Similarly, I would like to ask Dr Arnett whether he is ready to fill in for us the little gap Dr Massevitch referred to between the last systematically computed evolutionary model for a massive star and its final death.

Paczyński: I can only repeat that there are single massive Population I Wolf-Rayet stars surrounded by massive ring nebulae. This suggests that H-rich envelopes have been removed in a gentle fashion, not unlike the formation of a planetary nebula. Mass must have been lost in the red giant phase and the deficiency of red supergiants may be due to massive mass loss.

Schwarzschild: How does this happen?

Paczyński: Mass loss due to radiation pressure on dust grains can run at $10^{-5}\ M_{\odot}\ \mathrm{yr}^{-1}$ at least. Alternatively ionization processes in a distended atmosphere may be involved.

Schwarzschild: You might need both mechanisms.

Paczyński: I believe that there is considerable misunderstanding associated with the term 'planetary nebula'. Originally, in order to get a distance scale, Shklovsky adopted an *average* mass for a nebula as a fraction of solar mass. Later Harman and Seaton and O'Dell used a similar method to find distances and again they used $0.2\ M_{\odot}$ or $0.6\ M_{\odot}$ as an *average* mass for a nebula. But it must be emphasized that while the concept of 'average mass' may be used to derive a distance it cannot be used as an indication that all planetary nebulae have indeed identical masses. There are no observational data that I know that would indicate that all nebulae are equally massive. In fact circumstellar ionized nebulae are known to have masses from $10^{-3}\ M_{\odot}$ up to $10\ M_{\odot}$ or more (ring nebulae around single W-R stars). I think it is possible that radiation pressure on dust in the atmospheres of red supergiants is responsible for most of the mass loss, but perhaps the final mass loss is due to some

Tayler (ed.), Late Stages of Stellar Evolution, 103–104.

large scale instability of a whole envelope. Perhaps observations of young high density planetary nebulae and luminosous infra-red objects will help us to specify the real mechanism of mass loss.

Arnett: The gap mentioned by Dr Massevitch may not really be that large. My models start from helium burning and go all the way well into hydrodyamic core collapse. The cores are past the white dwarf maximum on their way to neutron stars. Work by me; Ivanova, Imshennik and Nadyozhin; and J. Wilson gives a fairly realistic picture of the collpase (if taken together). Falk and I have calculated supernova light curves from hydrodynamic models as have Ostriker and collaborators.

Bisnovatyi-Kogan: In the work by D. K. Nadyozhin and me (*Astrophys. Space Sci.* **15**, 353, 1972) the evolution of a 30 $M_{\odot}$ star was considered, taking into account the mass loss due to radiation pressure. Self consistent models with static core and outflowing envelope (3% of the total mass) were constructed with the boundary conditions far from the star being treated approximately. It was found that very intensive mass loss must occur leading to the loss of all the hydrogen envelope, with the remaining helium core $\sim 10\ M_{\odot}$ becoming a W-R star. It was indicated that, if this picture is right, a single W-R star must have a massive and extended transparent envelope $\sim$10–20 $M_{\odot}$. The observations of such envelopes about single W-R stars about which Paczyński has spoken seem to support our mechanism of W-R star formation and support the hypothesis of drastic mass loss. It seems at present that we have overestimated the mechanism of mass loss due to radiation pressure in the optically thick layer and that radiation pressure on dust grains must be an additional support to the mass loss. So, the mass loss from red supergiants must occur due to both these mechanisms acting together.

Woolf: The largest mass-loss rates observed for red supergiants are about $10^{-3}\ M_{\odot}\ \mathrm{yr}^{-1}$. This occurs in very rare luminous stars of type type M5Ia^{+}. Such stars are both very massive and very rare. There do not seem to be enough objects, which would have to persist for about 10^{5} yr, for this to be a major site of mass ejection for the most massive stars.

Appenzeller: Spectroscopic observations of some bright blue (and probably very massive P Cyg stars indicate mass loss rates in the order of $10^{-4}\ M_{\odot}\ \mathrm{yr}^{-1}$. Thus, massive stars may also lose a large amount of mass during a P Cyg stage and I wonder if the bright single Wolf-Rayet stars mentioned above could simply be 'evolved' P Cyg stars.

Massevitch to Arnett: I should be very happy if there was not gap between the last directly evolved star and the supernova but there still seems to be one.

Frantsman to Chiosi: The problem of differences of chemical composition of SMC, LMC and Galaxy may be solved with better results if both the differences of parameters of supergiants and cepheids are taken into account. The evolution of supergiants depends on too many free parameters and from the observational data for supergiants only it is very difficult to draw any conclusions concerning the chemical composition.