INTERMEDIATE AGE POPULATIONS

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ABSTRACT. Our understanding of asymptotic giant branch evolution has reached the point where the timescales are well enough known that realistic luminosity functions can be computed. The Mira and OH-IR star phases of stellar evolution truncate the AGB well before Reimers' Law mass loss exhausts the envelope. These luminosity functions allow us to compute the luminosity variance, which may be sensitive to the presence of intermediate age populations.

1. Introduction

In a distant stellar system an intermediate age population manifests itself most clearly through its asymptotic giant branch properties. Globular clusters have an AGB which stops at or around the luminosity of the red giant branch tip. This termination of the AGB is due to mass loss. Very young populations don't have an AGB at all, because $9M_\odot$ (or $5M_\odot$ models with convective overshooting) ignite their carbon cores non-degenerately. But between the limits of low mass stars and massive stars, the brightest stars in stellar populations are AGB stars. Here I plan to discuss progress in understanding the AGB in the last several years. Iben and Renzini (1983) remains the baseline review article in this area.

2. AGB Luminosity Functions in Magellanic Cloud Clusters

A census of stars in Cloud clusters has been published by Frogel, Mould and Blanco (1990), building on earlier work by Aaronson and Mould (1985) and Lloyd-Evans (1980). Figure 1 shows the luminosity functions accumulated in Searle, Wilkinson and Bagnuolo (1980) type. Type is a measure of age. Note the following things in Figure 1.

1. The AGB tip increases in luminosity in younger clusters, but does not reach the high luminosities anticipated with Reimers' (1975) mass loss rate with scaling parameter $\eta = 1/3$ (see Figure 7 of Iben and Renzini for those predictions).

2. The luminosity at which thermal pulses begin, as indicated by the presence of carbon and S stars, increases in luminosity in younger clusters. The parameterization by Lattanzio (1991) predicts this trend satisfactorily, and is used here in preference to the interpolation in Figure 7 of Iben and Renzini.

3. The following simple estimates of lifetime on the AGB give approximate (factor of two) agreement with the numbers of AGB stars per unit luminosity of the population in Figure 1. For thermal pulsing AGB stars: 1.3 Myrs/mag (Renzini 1978). For early

B. Barbuy and A. Renzini (eds.), The Stellar Populations of Galaxies, 181–190.

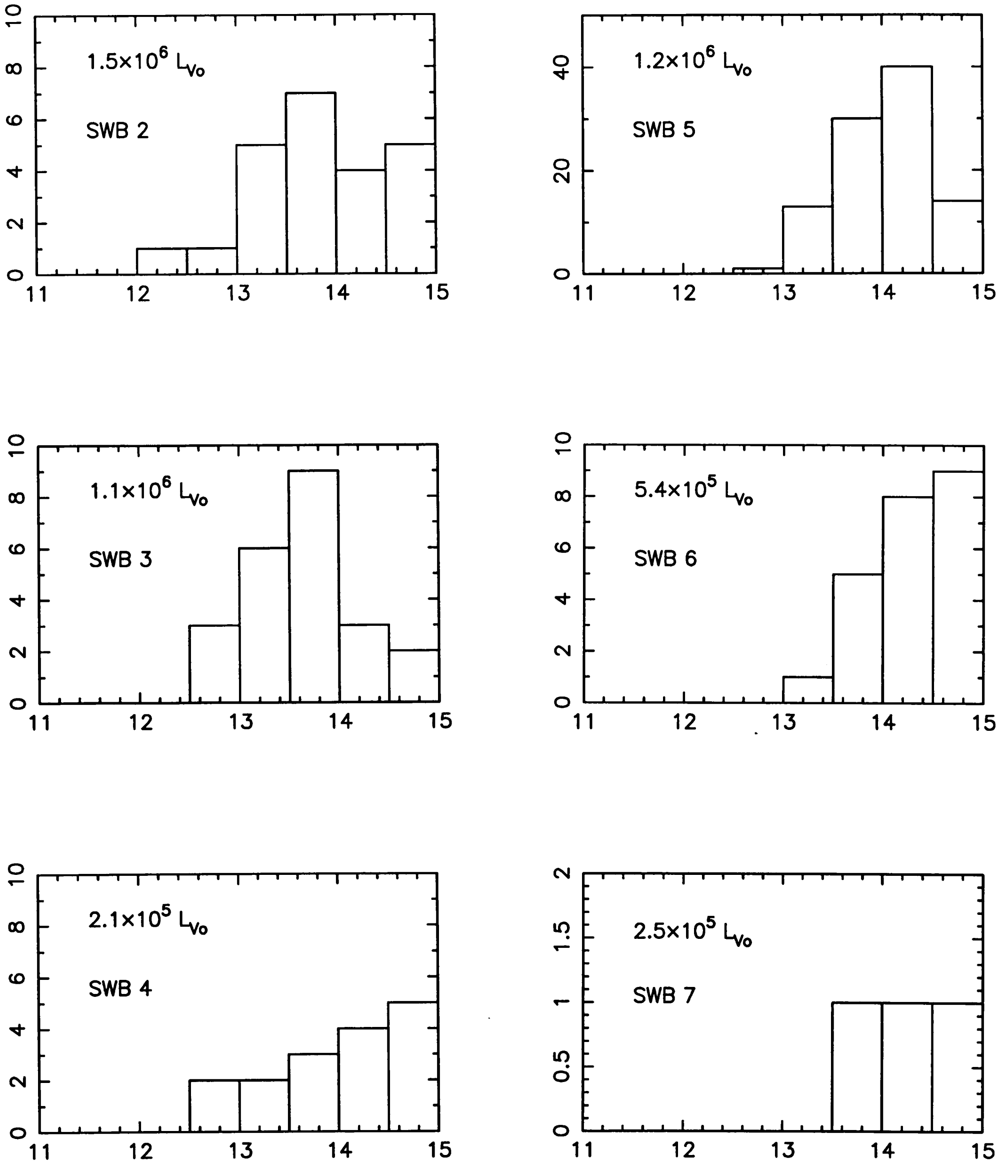

Figure 1. AGB luminosity functions for accumulated Magellanic Cloud clusters of different SWB type. The horizontal axis is apparent bolometric magnitude in the LMC. The total visual luminosity of the clusters in each panel is indicated. Source: Frogel *et al.* (1990).

AGB stars (before thermal pulses begin): 2.1 Myrs/mag (estimated here from the results of Lattanzio 1986).

3. The AGB Luminosity Function in Reid's LMC Field

Reid and Mould (1984) published an AGB luminosity function for a 15 square degree region of the Large Magellanic Cloud by selecting stars from Schmidt plates with V–I > 1.6 and $m_{bol} < 15$. This is shown in the upper part of Figure 2. There is some incompleteness at the faint end of this luminosity function, and some contamination by core helium burning massive stars (which are presumably much rarer than the 1–$2M_\odot$ stars dominating this distribution). The lower part of Figure 2 shows the Long Period Variable stars (LPVs) in this field studied by Reid, Glass, and Catchpole (1988). The factor of ten scale change between the top and bottom of Figure 2 emphasizes the small fraction of AGB stars that are Miras, and the correspondingly short lifetimes of AGB stars once they have become pulsationally unstable and entered the Mira phase. Still rarer are the "cocoon stars" (Reid 1991), optically unidentified IRAS sources in the same field. There is undoubtedly some incompleteness at the faint end of the cocoon star luminosity function. These luminosity functions are consistent with the notion that, once an AGB star's envelope has become unstable, its evolution is no longer controlled by burning on the inside, but rather by mass loss on the outside. Compared with the 10^6 year lifetimes associated with less advanced AGB stars, 10^5 year lifetimes should be associated with intermediate age Miras, and 10^4 years with cocoon stars.

Population synthesis models that include these evolutionary stages have recently been presented by Charlot and Bruzual (1990), based on a semi-empirical study of OH-IR stars by Bedijn (1988). These models predict a smaller AGB contribution to the total light of a simple stellar population of age 10^8 years, than did the Renzini and Buzzoni (1986) models based on Reimers' mass loss rates. Furthermore, they have been shown to fit the observations of Frogel, Mould and Blanco in this respect.

Simple population synthesis models can incorporate AGB evolution by including the following in their summation over all evolutionary phases:

1. Lattanzio's (1991) expressions for the core mass at the first thermal pulse,
2. Weidemann's (1987) initial-final mass relation,
3. the core-mass / luminosity relation of Lattanzio (1986) or Boothroyd and Sackmann (1988),
4. lifetimes of 1.3 Myr/mag (TPAGB) and 2.1 Myr/mag (E-AGB).

As an illustration, consider 7 epochs of star formation in the LMC, each a simple stellar population, corresponding to SWB types I–VII. If we employ the physical parameters (ages and metallicities) given for these populations by Frogel, Mould and Blanco, together with equation (14) of Renzini and Buzzoni (1986), and if we suppose the LMC has a star formation history such that there is 10^6 $L_{V\odot}$ in each of the 7 populations, we obtain a luminosity function shown in the top part of Figure 3. If we want to emphasize recent star formation and the peak in the star formation history ~2 Gyr ago, which almost everyone seems to see in the LMC, we can double the type I contribution and quadruple the type V contribution. We then obtain the luminosity function shown in the bottom part of Figure 3. The latter is approaching the shape of the observed luminosity function in Figure 2.

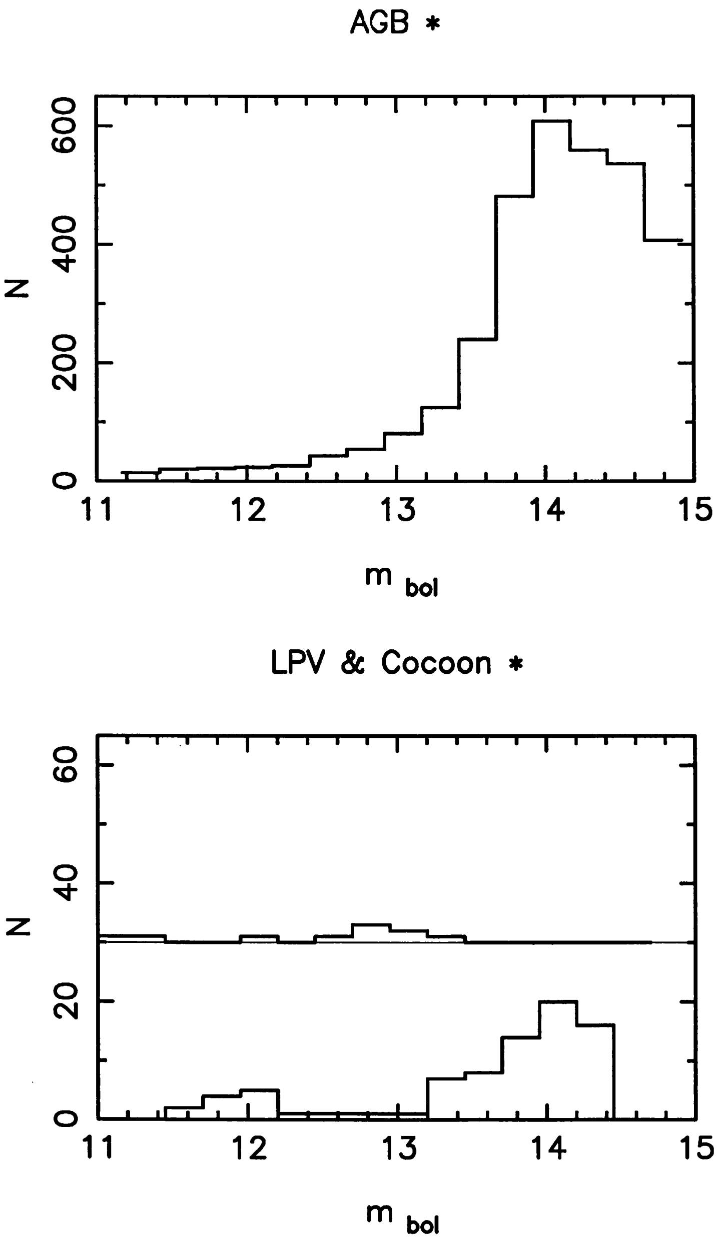

Figure 2. (above) Colour selected AGB luminosity function for Reid's LMC field. (below) LPV and "cocoon star" luminosity functions in this field. The IRAS sources are in the top part of the lower panel; the much more numerous LPVs in the bottom part.

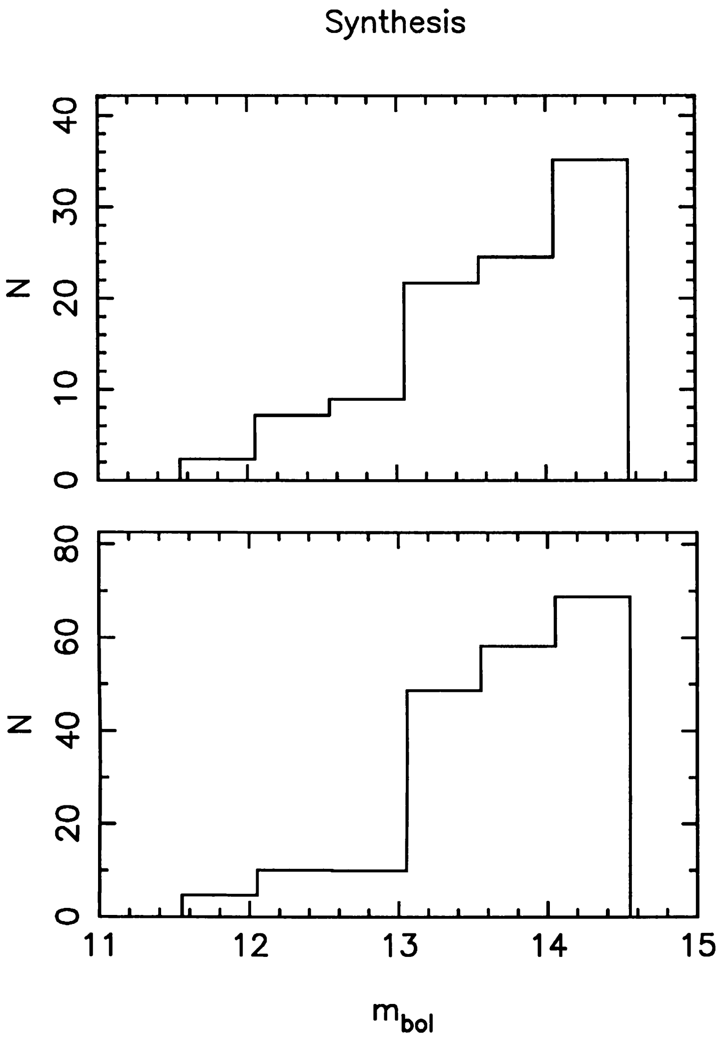

Figure 3. Synthesized AGB luminosity functions for the LMC. Top: assuming a luminosity of 10^6 $L_{V\odot}$ for all SWB types. Bottom: with enhanced type I and V populations.

4. Intermediate Age Populations in Ellipticals ?

Our desire to understand the stellar population of elliptical galaxies has tended to have a cosmological motivation. The traditional substitutes for inaccessible gE galaxies have been the bulge of M31 and its dE companion, M32. At this meeting R.M. Rich and W. Freedman have shown fascinating new evidence that both these objects have unexpectedly bright (M_{bol} = –5) AGB stars. Some of these stars are likely to be long period variables, and some are so red that measurement of their light curves will be required to establish $< M_{bol} >$. In respect of the bulge of M31 Rich and Mould (1991) considered four possible sources of these AGB stars, and it is worthwhile to review them here:

1. contamination by the disk of M31. Separation of the two components is generally an imprecise exercise in surface photometry, and M31 is no exception. Our best estimates were that the disk of M31 could account for between 17 and 56% of the observed bright AGB stars. But this fraction was not so well determined that we could confidently rule out the hypothesis that all the bright AGB stars actually belong to the disk. Study of fields closer to the center of M31 is feasible, and should resolve this problem, possibly soon. Presumably, the contamination hypothesis does not explain the observation of bright AGB stars in M32.

2. The bright AGB stars are super-metal-rich stars. Metal rich globular clusters have red horizontal branches and thus relatively thick post core helium burning envelopes, which can carry them to $< M_{bol} > = -4.5$ on the AGB (see Frogel and Elias 1983, 1988). Compare this with –3.6 for metal poor globulars. So, if we extrapolate this trend, what should we expect ? The answer is unclear, particularly since super-metal-rich compositions are now thought to exhibit blue horizontal branches (Pinsonneault *et al.* , this volume). Super-metal-rich composition is less likely to explain the bright AGB stars in M32, although Bica *et al.* (this volume) argue that the upper limit of the metallicity distribution in the M32 remains undetected.

3. The bright AGB stars are a 2–5 Gyr population. In the case of M32 this is exactly what population synthesis has been saying for years (see O'Connell 1986). Figure 1 would suggest approximately 4 AGB stars per magnitude at m_{bol} = 19.5 for a simple SWB type V population of 10^5 $L_{V\odot}$

4. Bright AGB stars result from stellar mergers. There are, of course, no bright AGB stars in globular clusters, even where blue stragglers are present, but this is probably just a result of small number statistics and the ratio of lifetimes of these phases (at least 10^3). Dwarf spheroidal galaxies may permit a better test of this hypothesis, and in the case of Carina it seems that an intermediate age population is required to explain simultaneously the bright AGB and the main sequence luminosity function (Mighell 1990). The dynamical conditions in globular clusters dwarf spheroidals, bulges, and ellipticals are very different, and it is quite a challenge to any theory of stellar mergers to populate the HR diagram appropriately and retain some correspondence with observations.

5. The effect of bright AGB stars on the luminosity variance statistic

If the traditional motivation for the study of old stellar populations is cosmological, a new twist has appeared recently in the discovery by Tonry and Schneider (1988) that a statistic of the luminosity function is measureable in a partially resolved population. That statistic is the variance of the luminosity function, and it is observable, when other noise sources

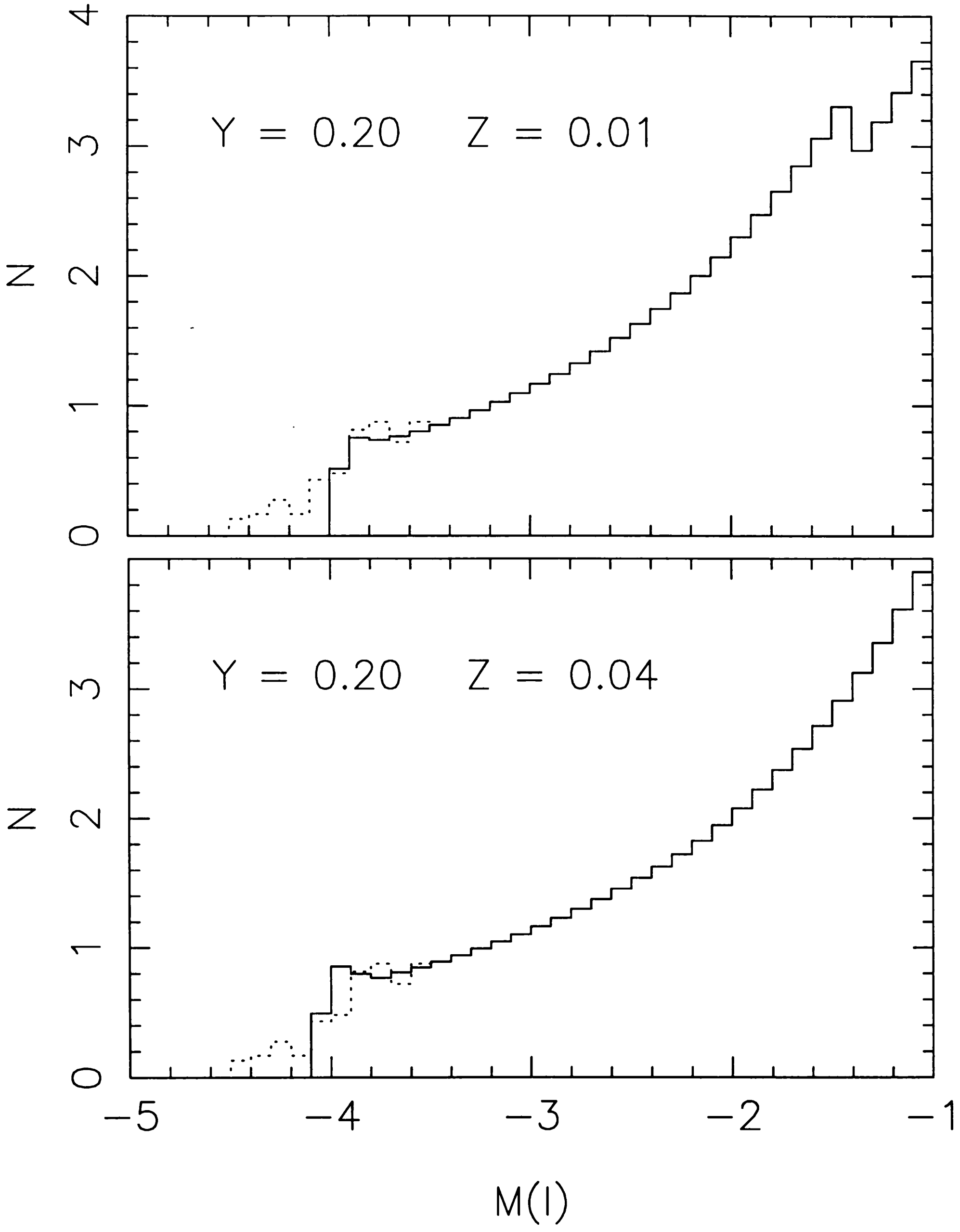

Figure 4. Revised Yale Luminosity Functions for $M_I < -1$ (solid lines). Observed M32 luminosity function (Freedman 1989) for $M_I < -3.5$ (dashed line).

are appropriately small and distinct, as the variation in the number of stars per pixel in the sample that one draws when imaging a stellar population. The luminosity variance, $\overline{m}_I$, is a very tight function of the color of elliptical galaxies (Tonry 1991), which may appear as something of an embarrassment for the theory of stellar populations, as the sense of the color dependence is the opposite of the prediction (Tonry, Ajhar and Luppino 1990), if metallicity variation is the source of the color range. Fortunately, calculations confirm Tonry's suggestion that the origin of this discrepancy is bolometric corrections to cool stars. If we substitute the quadratic relation of Bessell and Wood (1984) between BC_I and V–I for the linear relation adopted in the Revised Yale Isochrones and Luminosity Functions (Green, Demarque and King 1987), we obtain the results shown in the first 3 rows of Table 1: super-metal-rich stellar populations of age 17 Gyr are indeed expected to have a lower luminosity variance at I than their less metal rich counterparts. The observed difference in $\overline{m}_I$ between M31 and M32 is 0.35 ± 0.08 mag, a large fraction of the 0.42 mag difference between predictions for Z = 0.04 and Z = 0.01 in row (3) of Table 1. I must caution that these calculations should not be used to calibrate $\overline{m}_I$, as Wood and Bessell's bolometric corrections are only valid for the average composition of the stars they observed. Moreover, the treatment of the post giant branch evolution adopted here is rudimentary at best. A helium abundance Y = 0.2 and Salpeter initial mass function were employed. Mean Kron-Cousins V–I colors of the model populations are given in the second part of the table.

Table 1: Calculated Luminosity Variance

$\overline{m}_I$	Z = 0.01	Z = 0.04	
Yale	–1.85	–2.10	(1)
Yale + AGB	–2.07	–2.26	(2)
Modified BC	–1.84	–1.42	(3)

V–I	Z = 0.01	Z = 0.04	
Yale	1.12	1.40	(1)
Yale + AGB	1.15	1.43	(2)

A more interesting exercise in the present context is to add in the bright AGB stars seen in M32 to the theoretical luminosity functions. This is shown in Figure 4, in which the dashed curve represents the luminosity function of M32 observed by Freedman (1989), normalized to the Yale luminosity functions where they overlap. Table 1 shows that stars brighter than the termination of the Yale giant branches cause a 0.2 mag increase in the luminosity variance. This is not surprising, as these AGB stars are the brightest stars in the galaxy, and therefore most effective in increasing the variance. We conclude that, whatever their source (and each of the four items listed in the previous section is a candidate), bright AGB stars must be factored into calculations of luminosity variance. If bright AGB stars occur in some elliptical galaxies and not in others, the luminosity variance will reflect this phenomenon.

6. References

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DISCUSSION

RENZINI: For over ten years I've been troubled with the problem of the missing bright AGB stars, and was unable to find a sensible solution. For example, I was not satified with *ad hoc* appeals to extra mass loss and the like. Having said this, I would like also to say that the solution to the problem may finally have been found. In a recent paper in A. & A. Blocker and Schonberner report evolutionary calculations of a thermally pulsing $7M_{\odot}$ star, in which the mixing length parameter is set in such a way for the so-called "envelope-burning" process to occur. With great surprise the models *do not* follow the famous core-mass luminosity relation, but evolve quickly to very high luminosities, spending a nearly ten times shorter time between M_{bol} = −6 and −7 than models assuming the canonical core-mass luminosity relation would predict.

MOULD: All the progress in AGB theory in the last few years has come about through the explicit calculation of evolutionary models rather than trying to guess the results for one set of parameters from those for another, and this is no exception. Observationally and theoretically, the high mass end of AGB evolution is now the frontier. The acceleration of high mass AGB stars up the AGB after ignition of envelope burning overcomes the objection that Reid and I made to this process, namely that there is a deficiency of high luminosity M stars as well as C stars. There are also the Lithium observations of Lambert and Smith in luminous AGB stars to support the reality of envelope burning.

Most of the AGB stars in the LMC, however, are older than 10^8 years, of course, and of too low a mass for envelope burning. For these stars I'm confident that the processes I've described of early termination of AGB evolution following the onset of Mira pulsation are required to explain the luminosity distribution.