STELLAR POPULATIONS IN THE GALACTIC BULGE

H.J. HABING
Sterrewacht, Leiden

1. What we want to know, and why.

In this review I discuss stars in the bulge of our Milky Way, but I exclude stars within a few parsec from Sgr A West; they are the subject of other reviews at this Symposium. We should, however, not forget that there may be an intimate connection between the central cluster and the bulge: bulge stars may eject matter that feeds the monster at the center and eruptions by this monster may have an important effect on the bulge.

Over the last years several separate reviews and several conferences have been dedicated (at least in part) to bulges and to the bulge of our Milky Way Galaxy: see references below. It is quite a task to read all reviews on the topic! King's stimulating introduction to the Ghent symposium on galactic bulges leads us directly into what we want to know, and what we don't: "The problems of the bulge fall into four general areas: what is there, how it is distributed, how it moves and how it got that way". Phrased in a mathematical way, we want to know the distribution function $f(\mathbf{x}, \mathbf{v})$ for each astrophysical object (star, cluster, planetary nebula) defined by an age, a metallicity and a ZAMS–mass (and ideally: with a multiplicity index). Here $\mathbf{x}$ is the position vector in galactic coordinates and $\mathbf{v}$ the 3-d velocity vector. Ultimately this knowledge will give us the mass–distribution in the bulge and the formation history.

I owe to King's introduction an obvious warning, that however needs repetition: the galactic center is not only a place of its own, but also the center of other galactic components. Thus the discovery of halo objects inside the bulge may have no other meaning than that this place is the center of the halo. Are the metal–poor and the metal–rich stars near the center accidentally together or is there a relation? To answer such type of

L. Blitz and P. Teuben (eds.), Unsolved Problems of the Milky Way, 317–327.

questions we need first a good insight in the distribution functions $f(\mathbf{x}, \mathbf{v})$ of metal–rich and metal–poor stars.

In the concluding remarks of my talk I will check the recent progress against King's four question areas. At this place allow me this side remark: if an unresolved scientific problem can be formulated in such a complete set of very general questions as given by King, we do not yet know a hell of a lot.

2. What we learned in the last few years.

2.1. COLOUR–MAGNITUDE DIAGRAMS (CMD'S).

Star counts made in one colour have been obtained by several authors, but I will not discuss them here; CMD's are more informative and I gave their discussion higher priority. Surface photometry by the Spacelab Infrared Telescope (Kent *et al.*, 1991) and especially by COBE will be discussed, I presume, elsewhere is this book.

Going from brighter to fainter stars the appearance of the CMD's is dominated successively by foreground main-sequence stars in the galactic disk, red giants in the bulge, horizontal–branch or core–helium burning stars (especially red HB stars), and main sequence stars in the bulge. Because our understanding of the red giant branch and of the HB is well advanced some conclusions can be drawn without a discussion of the faintest objects, the main sequence stars in the bulge.

One of the new, and perhaps firm conclusions is that the number of foreground disk stars is smaller by factors of order two than those predicted by the Bahcall and Soneira model. The shortage of foreground stars becomes obvious at the higher latitudes (let me say above 5° latitude) where the numbers of bulge stars have dropped strongly (Paczynski *et al.*, 1994; Ng *et al.*, 1994; Bertelli *et al.*, 1994).

2.1.1. *CMDs in wavelength bands below 1 μm.*

Colour–magnitude diagrams in the V, R, I–bands have appeared of stellar fields at different longitudes and latitudes containing large numbers (tens of thousands) of stars measured photometrically down to sometimes 21st or 22nd magnitude with accuracies of a few hundredths of a magnitude. CCD's yield the best measurements, but photographic surveys are still significant, even when they go much less deep (Ng, 1994). The CMDs are affected by incompleteness because the surveys are often confused by crowding of the stellar images at the fainter magnitudes; therefore there is a role in this game for HST (after the repair).

The diagrams contain a mix of main-sequence and evolved (FGB and HB) stars of varying distance and extinction and of different metallicities.

Often the true nature of an individual star is unknown: is it a reddened G dwarf in the galactic disk or a distant G giant in the bulge? The statistical analysis is thus more complex than those of stellar clusters, although cluster CMDs are at the heart of all analyses. The extinction has to be known as a function of distance and a galactic model is needed to describe the distribution of the stars in space. The Bahcall and Soneira model is often used but it is inadequate at low latitudes (for which it was never designed). Recently a new galactic model has been proposed by the Padua group of Chiosi (see Ng *et al.*, 1994) as part of a software package that predicts galactic field CMDs and is called "HRD–GST": "a Hertzsprung–Russell Diagram Galactic Software Telescope". The package consists of three parts: I. A library of evolutionary tracks for stars of different masses and different helium and metal abundances; II. A galactic model that defines the spatial distribution of the stars and the extinction; III. A simulator that creates CMDs from the two previous parts by a Monte Carlo process. Predicted and observed CMDs are compared by some statistical technique and the parameters of the galactic model are varied until a satisfactory fit is obtained. Application of this tool requires a good confidence in the library of evolution tracks, which has been obtained by checking the library against cluster observations. However, as the galactic center is likely to be a high–metallicity environment the lack of observed CMDs of super–metal rich clusters is a weakness. For example, strong blanketing effects e.g. in the V– and I– band observations of red giants are believed to exist, but have not at all been quantitatively described. Another weakness of the computed CMDs is that they do not contain multiple stars, although in reality these will be present in significant numbers.

I now summarize some recent results:

CMDs have been measured mostly in V and I of several metal–rich globular clusters in the inner Galaxy; from the same CCD frames CMDs were produced of field stars. Ortolani *et al.* (1993a and 1993b) give a summary of these field CMDs and Bertelli *et al.* (1994) discuss the results further (and revise at least one of the earlier conclusions).

Extinction plays a major role in shaping the diagrams, and not only the total amount of extinction is important, but also its distribution along the line of sight. In the end Bertelli *et al.* conclude that the two CMDs at (respectively) $l = -31°$ and $12.9°$ contain mainly disk stars, but in the field near $l = -2.4°$ one recognizes many bulge stars (red giants and clump stars). By removing the disk stars a CMD is produced for this field that contains only bulge stars. An age of 12.5 to 15 Gyr can then be assigned to the bulge stars and a star formation rate that decreased exponentially with an e-value of 2.5 Gyr. A conclusion that satisfied me greatly is the existence of a hole in the galactic stellar disk with a radius of 2.5 kpc around

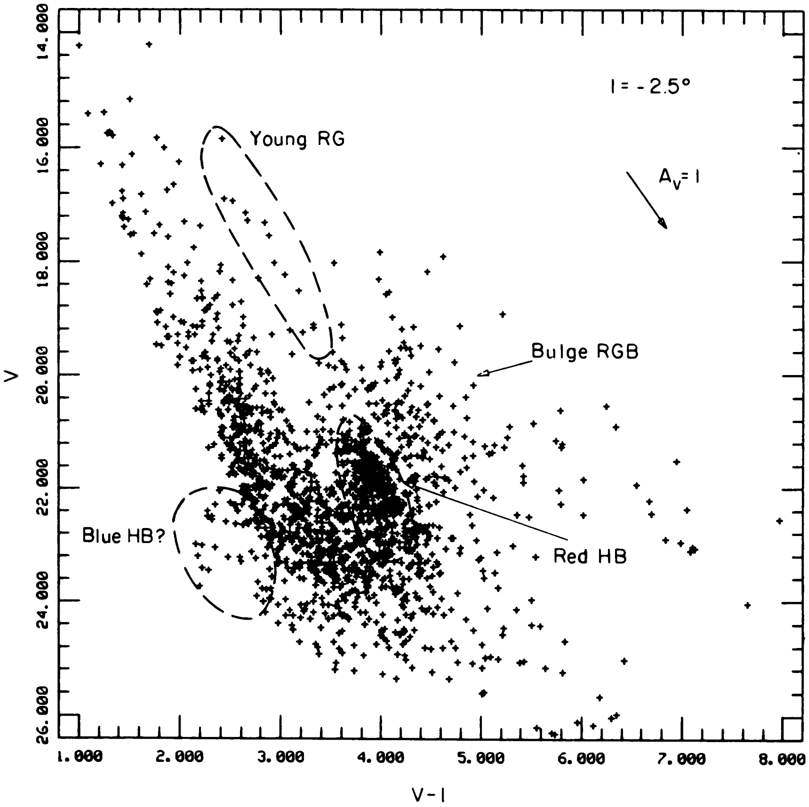

Figure 1. V versus $(V - I)$ diagram of field stars near the open cluster Terzan 1 at $l = -357.5°$, $b = +1.0°$; Ortolani *et al.*, (1993b)

the galactic center; this hole agrees nicely with that found in the OH/IR star distribution (thus: in the distribution of the most luminous AGB stars; Baud *et al.*, 1981; Blommaert *et al.*, 1994). The hole is encircled by a ring of disk stars. Ages between 1 and 7 Gyr are assigned to the disk stars, based on the ratio between the numbers of main-sequence and giant stars. A few much younger stars are also present.

V vs. $V - I$ diagrams of 300,000 stars in Baade's window have recently been published by the OGLE consortium (Paczynski *et al.*, 1994). This is a side product from the search for dark matter via mini-gravitational-lens effects. Paczynski will discuss these observations in one of the next invited reviews, and I skip discussing the interesting CMDs. But I note the conclusion that the number of foreground stars (disk stars) seem to disappear abruptly at a distance of only a few kiloparsec. This conclusion agrees in general terms with those reached by others (see above) but there are differences that will hopefully be resolved in the near future.

A first CMD based on HST measurements, before its repair, in Baade's window been presented by Holtzmann *et al.* (1993). This is a crowded field and it is no surprise that the conclusions reached (a.o. that the bulge contains star less than 10 Gyr old) differ from e.g. those of Bertelli *et al.* (see above).

2.1.2. *CMD's in the near–infrared.*

In the near-IR (J, H, K, L) one can penetrate all the way to the galactic center; extinction continues to cause problems but is no longer as devastating as it is below 1 μm. The near IR bands have the disadvantages of less sensitivity and a smaller number of pixels per exposure; both disadvantages are now rapidly disappearing. An early piece of work is by Catchpole *et al.* (1990) who mapped an area of $1° \times 2°$ around the center with a photometer working simultaneously at J, H, K, but with only one pixel per band and with poor angular resolution ($6'' \times 12''$). The detection limit $K = 12$ and thus only bright stars are detected ($M_K \leq -2.5$), probably all late–type giants; the brightest stars ($K < 7.0$) cluster more strongly to the center than the fainter giants.

Ruelas–Mayorga and Teague (1993) give a CMD of K versus $J - K$ of ≈ 160 stars down to $K \approx 11$ in Baade's Window showing a giant branch. This work is surpassed in importance by Davidge (1991) who produces a CMD from J, H, K–measurements on 76 stars in Baade's Window down to $K \approx 16$. The RGB is clearly seen; it matches very well the RGB of 47 Tuc and of M67 (if these are shifted according to distance and extinction differences). Horizontal Branch stars appear below $K \approx 13.2$. There are less HB stars with respect to the red giants than as seen in the I–band.

Nagata *et al.* (1993, 1994) made a survey simultaneously in the H and the K band of a strip of $112' \times 18'$ containing the galactic center and discuss more extensive photometry (in a few cases to 20 μm) of a sample of 50 stars brighter than K=9.45; this sample contains *all* stars with $K < 7.6$. Several objects have $M_{bol} < -5.0$ ($L > 7700\ L_{\odot}$), which is also the maximum for M giants in the bulge (Frogel and Whitford, 1987). The number of bright objects is consistent with an exponential disk and there is no indication of a concentration of M–supergiants in the central region. A few objects could be very young.

2.2. ABUNDANCES AND AGES.

There are several indications that the bulge contains stars of much higher metallicity than the Sun, but the indications are all indirect: a detailed spectroscopic analysis of stellar atmospheres has been lacking until recently.

The stars easiest detected in the bulge are M–giants, but unfortunately their atmospheric structure is poorly known and until now a detailed spectral analysis has been impossible; a breakthrough may have been achieved recently by Tsuji *et al.* (1994) in their detailed analysis of SiO–abundances in bright and nearby M-giants.

McWilliam and Rich (1994) analyse spectra of 12 K giants in Baade's Window taken between 617 and 760 nm with a resolution of $R \approx 17000$. Judging from their magnitude and their radial velocity the stars are not in the foreground and belong almost certainly to the bulge. McWilliam and Rich perform a detailed spectroscopic analysis. The conclusion is that the distribution of [Fe/H] abundances of stars in Baade's Window agrees very well with the distribution in solar neighborhood stars. The same is true for Ca and Si, but Mg and Ti are enhanced by about 0.3 dex. The [Fe/H] abundances derived before by Rich (1990) are about 0.3 dex (a factor of 2) too high; this is mainly because Mg played a tricky role: the [Mg/Fe] abundance is higher in the bulge stars than in the solar neighborhood stars. The conclusion of solar–like Fe abundance resolves a few outstanding problems; for example the conclusion by Davidge (1991) that the giant branch in K vs. $J - K$ CMDs of Baade's Window agrees so well with that of 47 Tuc; but solar–like abundances contradict (indirectly) abundances obtained by others. These differences are discussed at length in the McWilliam and Rich paper and lead to the conclusion "that the others were wrong"; the arguments convinced me but some further discussion by "*affecionados*" is to be expected.

In detailed analyses like those by McWilliam and Rich one element is outstandingly absent: helium. Yet helium plays a key role in determining the stellar properties, for example in the determination of the age of a red giant. Indirectly one may estimate the helium abundances from the ratio between horizontal branch stars and red giants, a technique propagated already by Schwarzschild (1970) in his George Darwin lecture. In a recent paper Renzini (1994) discusses this ratio for the bulge stars; its value is read from the OGLE CMD. There appear to be relatively fewer red giants in the bulge than e.g. in globular clusters and this leads Renzini to the suggestion that the helium abundance is enhanced in the bulge; he estimates Y to be between 0.31 and 0.35. Another consequence is that these HB stars could be very old, at least as old as the globular clusters.

Other old stellar objects in the bulge that permit detailed spectroscopic analysis are the planetary nebulae. Clegg (1993) surveys recent abundance determinations in the Bulge, elsewhere in the Galaxy and in other, nearby galaxies. Concerning planetary nebulae in the bulge solar abundances are found.

There are other, more indirect means for the determination of abundances: the CO– and H_2O–indices; the absence of carbon stars; the ratios of number densities of FGB (First Giant Branch), RHB, BHB stars; Preston's ΔS for RR Lyrae. I like to add a new one to this list: the v_{out}–method for OH/IR stars, discovered in model calculations of the transfer of momentum from photons to dust to gas in circumstellar envelopes (Netzer and Elitzur, 1993; Habing, Tignon and Tielens, 1994); the results are supported by several observational facts. The models show that the mass loss rate, $\dot{M}$, of a Mira or OH/IR star is determined by the pulsational properties of the star and *not* by the light pressure on grains, but the light pressure does determine the *momentum* obtained by the outflow, $\dot{M}v_{out}$. As a consequence the outflow velocity, v_{out} is determined by two factors: the luminosity L and the dust–to–gas ratio, δ, at least in stars with a high value of $\dot{M}$; the relation is $v_{out} \propto \delta^{0.5}L^{0.25}$ (Habing *et al.*, 1994). Thus if one knows L and v_{out}, one derives δ. In OH/IR stars the dust–to–gas ratio is determined by the Si–abundance and δ is a measure for [Si/H].

2.3. VARIABLES AT THE TOP OF THE AGB AND THEIR OFF–SPRING.

Long Period Variables (Mira variables, "IRC Miras" and OH/IR stars) are very bright AGB stars. Planetary Nebulae develop at constant luminosity from these top-AGB stars. For a thorough discussion of the presence of these populations in the bulge I refer to the conference proceedings listed at the end of this review.

Given the little time available I turn my attention to the distribution of OH/IR stars in the innermost parts of our Milky Way, that is within 200 pc from the center. OH/IR stars are direct relatives of Miras and these two kinds of Long Period Variables overlap in luminosity between 5000 and 8000 $L_\odot$, that is for M_{bol} between -4.5 and -5.1; Miras with longer periods (and higher luminosity) equal in luminosity the OH/IR stars of shorter periods (and lower luminosity) and probably the Miras develop into these OH/IR stars. A considerable fraction of the OH/IR stars (4 out of 17 measured by Blommaert, 1992; 8 out of 17 measured by Jones *et al.*, 1994) are brighter than M_{bol}= -5.1 and this appears to be the upper limit of the stars detected by optical means in the various windows. Such luminous AGB stars must be, at least in part, rather young (say younger than 1-2 Gyr)– if the stars are single. Renzini (1992) has suggested that the OH/IR stars result from mergers of double stars and thus may be much older than this low age; the small number of these stars is to be expected under this merged–double hypothesis. An interesting case is the star that is most luminous (by far): OH 359.762+0.120; M_{bol}=-7.2 or L= 60,000 $L_\odot$(Jones *et al.*, 1994), P = 760^d, v_{out}= 15 km/s. The star cannot be a foreground object, because the 1612 MHz (18 cm) image of the maser is strongly deformed (= smeared out) by interstellar scintillation and this effect, we think, occurs only close to the galactic center (van Langevelde, *et al.* 1992; Frail *et al.* 1994). Renzini's suggestion is quite welcome in explaining the high luminosity of this star. Yet, I feel some reservation (see below) against applying the merged–double explanation to *all* OH/IR stars.

After a search lasting several years Lindqvist *et al.* (1991, 1992) have now obtained a sample of 136 OH stars within 150 parsec from the galactic center. The sample is complete down to a well defined sensitivity limit and as such it is probably the only complete stellar sample known in this inaccessible region of the Galaxy. Subsamples have been monitored in the near IR (Jones et al, 1994) and in the maser line (van Langevelde *et al.*, 1993) and prove that the majority, though not all, are long period variables with periods up to 800 days. Infrared measurements made from the ground lead to reasonably accurate estimates of the stellar luminosities (Jones *et al.*1994; Blommaert, 1992). If this sample is divided in two subsamples based on the value of the outflow velocity, v_{out}(an easily and accurately measured quantity) there are pronounced differences in the distribution of these two samples in the plane of the sky and in the longitude/velocity diagram:

—Stars with lower expansion velocities are distributed in a spheroidal distribution with a flattening of 0.7. The radial velocities may correlate with longitude, but the slope of the regression line is small (0.01 km/s/pc). Its value agrees nicely with that seen in Mira variables (e.g. in Baade's Window) or in the recent near IR measurements of M–giants by Blum *et al.* (1994). The dynamical model by Kent (1992) accounts quite well for these velocities and for the spatial distribution by assuming a relaxed stellar population with an isotropic velocity distribution and small systematic rotation, enough to flatten the bulge by a modest amount.

—In contrast to the stars with lower outflow velocities, one finds for the stars with higher outflow velocity a flatter distribution on the sky and a rapid rotation around the galactic center like a solid body with a speed of about 1 km/s/pc; thus a rotation much faster than Kent's spheroid.

Kinematic differences prove that these two subsamples of OH/IR stars represent two different galactic populations. The distinction between the populations is made on basis of by the outflow velocity. As mentioned above a difference in δ or L or in both determines the outflow velocity, v_{out}. The luminosities of several OH/IR stars have been determined via broadband photometry between 4 and 20 μm (Blommaert, 1992); the stars with higher v_{out} have somewhat higher luminosity, but not enough to explain the difference in v_{out} between the two samples. The conclusion is that the stars with larger v_{out} have higher dust–to–gas ratios and higher Si–abundance. Thus the stars with larger outflow velocity behave as if they have formed out of a disk of (significantly enriched) gas and have kept their state of motion since then, and that this formation was an event different from and more recent than the one that formed Kent's spheroid: the OH/IR stars near the center are a mix originating from two different populations, each with its own formation history.

To close off this subject allow me a few additional remarks.

(i) M-giants near the center studied ,o far all appear to belong to the flattened spheroid discussed by Kent. Where are the M-giants/precursors of the OH/IR stars with large outflow velocities? If Renzini (see above) is right about the fact hat the OH/IR stars are mergers from a population of old stars with maximum AGB luminosity M_{bol}=-5.1, then the high outflow–velocity OH/IR stars should have also many counterparts of lower luminosity. Where are they?

(ii) Each OH/IR star appears to have a SiO-maser but the reverse is not true: there are many more stars with an SiO and without an OH maser than stars that have both. The somewhat small sample of OH/IR stars can thus be expanded by a significant factor by concentrating on SiO masers. Izumiura *et al.* (1994) have just completed a study with the Nobeyama telescope and detected SiO masers in a large number of bulge LPV's. Clearly here is a new opening to the field of research of LPV's in the galactic bulge.

2.4. BULGE AND BAR.

If our Galaxy contains a bar (and the kinematics of the gas in the inner Galaxy clearly point in that direction) it will be important to find out what stellar population it contains. The only "definite suggestion" (apologies for the contradiction) has been made by Whitelock (1993) who finds a concentration of Long Period Variables associated with the bar.

3. What remains to be learned.

There has been significant progress in recent years. The large and thorough work by McWilliam and Rich has now established somewhat more firmly that the bulge or at least the K–giants in Baade's Window have Fe abundances comparable to those in the solar neighborhood but a higher Mg/Fe abundance ratio. This conclusion about solar type abundances then agrees with those about the abundances in bulge planetary nebulae. The solar metallicity conclusion solves other outstanding problems but disagrees with much earlier work, mostly based on indirect and modestly accurate metallicity estimators. McWilliam and Rich's words will not be the last to be said about abundances in the bulge. Deep Hertzsprung–Russell diagrams for bulge stars, with the foreground stars removed, and in fields in different directions are now available; detailed studies on individual stars in these diagrams are the next step (e.g. detailed spectroscopy of red horizontal branch stars in the bulge). It is to be hoped that accurate spectroscopic determinations of metallicities in M–giants will become doable. Whereas Kent's spheroidal model explains most of the bulge data, one finds in part of the OH/IR stars a population that is clearly different; it seems to have a high metallicity and an origin different from that of Kent's spheroid.

4. A concluding and irrelevant remark.

Jan Oort established his fame in 1927, in his 27th year, when he concluded that stars in the solar neighborhood rotate around a distant center in Sagittarius. This conclusion is still a major anchor that secures the study of the Galaxy we live in. For about 65 years Oort continued to solve problems of the Galaxy. But clearly he did not solve all of them, otherwise we would not have a symposium with the title "Unsolved problems of our Milky Way". To me there is irony in the fact that we dedicate a symposium with this title to him, who has solved more galactic problems than anybody else; it almost looks as if we have a cause for complaints. Well, I may find this ironical, but I think that he would have felt differently and that is what counts.

5. Conference Proceedings and general review lectures:

"Bulges of Galaxies", 1990, eds. B.J. Jarvis, D.M. Terndrup (ESO publications).

"The Stellar Populations of Galaxies", IAU Symposium # 149, 1992, eds. Barbuy and Renzini, Kluwer Academic Publishers, Dordrecht.

"Galactic Bulges" IAU symposium # 153, 1993, eds. H. Dejonghe and H.J. Habing, Kluwer Academic Publishers, Dordrecht.

"Planetary Nebulae", IAU Symposium # 155, 1993, eds. R. Weinberger, A. Acker, Kluwer Academic Publishers, Dordrecht.

"The Nuclei of Normal Galaxies: Lessons from the Galactic Center" (Conference at Schloss Ringberg), 1994, eds R. Genzel and A. Harris, NATO ASI series, Kluwer Academic Publishers, Dordrecht.

"The Center, Bulge and Disk of our Milky Way", 1992, ed L. Blitz, Kluwer Academic Publishers, Dordrecht.

References

Baud, B., Habing, H.J., Matthews, H.E., Winnberg, A. (1981), *A.& A.*, 95,p. 156
Bertelli, G., Bressan, A., Chiosi, C., Ng, Y.K., Ortolani, S. (1994), *A.& A.*, submitted
Blommaert (1992),*thesis, Leiden University*
Blommaert, J.A.D.L., van Langevelde, H.J., Michiels, W.F.P. (1994), *A.& A.*, 287,p. 479

Blum, R.D., Carr, J.S., DePoy, D.L., Sellgren, K., Terndrup, D.M. (1994), *Ap.J.*, 422,p. 111

Catchpole, R.M., Whitelock, P.A., Glass, I.S. (1990), *Mon. Not. R.A.S.*, 247, p. 479

Clegg, R.E.S. (1993), *in "Planetary Nebulae", IAU Symposium # 155, eds. R. Weinberger and A. Acker*,Kluwer, Dordrecht,p. 549

Davidge, T. (1991), *Ap. J.*, 380,p. 116

Frail, D.A., Diamond, P.J., Cordes, J.M., van Langevelde, H.J. (1994), *Ap.J.let*, 427,p. L43

Frogel, J.A., Whitford, A.E. (1987),*Ap. J.*, 320,p. 190

Greggio, L., Renzini, A. (1990), *Ap. J.*, 364,p. 35

Habing, H.J., Tignon, J., Tielens, A.G.G.M. (1994), *A.& A.*, 286,p. 523.

Holtzman, J.A., Light, R.M., Baum, W.A., Worthey, G., Faber, S.M., Hunter, D.A., O'Neil, E.J., Kreidl, T.J., Groth, E.J., Westphal, J.A. (1993), *Astron. J.*, 106, p. 1826

Izumiura, H., Deguchi, S., Hashimoto, O., Nakada, Y., Onaka, T., Ono, T., Ukita, N., Yamamura, I. (1994), *Ap. J.*, in press

Jones, T.J., McGregor, P.J., Gehrz, R.D., Lawrence, G.F. (1994), *Astron. J.*, 107, p. 1111

Kent, S.M. (1992), *Ap. J.*, 387, p. 181

Kent, S.M., Dame, T., Fazio, G. (1991), *Ap. J.*, 378,p. 131

Lindqvist, M., Winnberg, A., Habing, H.J., Matthews, H.E. (1991), it A.& A. Sup. Ser.,bf 92,p. 43

Lindqvist, M., Habing, H.J., Winnberg, A., (1992),*A.& A.*, 259, p. 118

McWilliam, A., Rich, R.M. (1994), *Ap. J. Sup*, 91,p. 749

Nagata, T., Hyland, A.R., Straw, S.M., Sato, S., Kawara, K. (1993), *Ap. J.*, 406,p. 501

Nagata, T., Kobayashi, N., Sato, S. (1994), *Ap.J.let*, 423,p.L113

Netzer, N., Elitzur, M. (1993), *Ap.J.*, 410, p. 701

Ng, Y.K. (1994), *thesis, Leiden University*

Ng, Y.K., Bertelli, G., Chiosi, C., Bressan, A. (1994), *A.& A.*,submitted

Ortolani, S., Bica, E., Barbuy, B. (1993a), *A.& A.*, 267,p. 66

Ortolani, S., Bica, E., Barbuy, B. (1993b), *Ap. J.*, 408,p. L29

Paczynski, B., Stanek, K.Z., Udalski, A., Szymanski, M., Kaluzny, J., Kubiak, K., Mateo, M. (1994), *Astron. J.*, 107,p. 2060

Renzini, A. (1994), *A.& A. Lett.*, 285,p. L5

Rich, R.M. (1990), *Ap. J.*,*362*,p. 604

Ruelas-Mayorga, R.A., Teague, P.F. (1992), *A.& A. Sup. Ser.*, 93,p. 61

Schwarzschild, M. (1970), *Quart. J. R.A.S.*, 11,p. 12

Tsuji, T., Ohnaka, K., Hinkle, K.H., Ridgway, S.T. (1994), *A.& A.*,submitted

van Langevelde, H.J., Frail, D.A., Cordes, J.M., Diamond, P.J. (1992), *Ap.J.*, 396,p. 686

van Langevelde, H.J., Janssens, M., Goss, W.M., Habing, H.J. Winnberg, A. (1993), *A.& A.*, 101,p. 109

Whitelock, P.A., *in "Galactic Bulges", IAU Symposium # 153*, eds. H. Dejonghe and H.J.Habing,Kluwer, Dordrecht, p. 39