Structure of the Core of Globular Clusters

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Introduction

There are numerous astrophysical arguments to stimulate an observer who wishes to study the poorly known central parts of globular clusters. Two considerations are particularly exciting. The theories of dynamical evolution of these stellar systems systematically predict the development of a central singularity; now, if it exists, what is its physical counterpart? In the observational field, we know that at least 15 globular cluster cores are associated with X-ray sources. Such phenomena occur preferentially in concentrated globular clusters. High spatial resolution is needed to disentangle individual stars in the central overcrowded fields. We are currently observing several concentrated globular clusters at Pic-du-Midi Observatory where excellent seeing is not rare. The splendid observations reported at La Silla with the 1.5 m Danish telescope (THE MESSENGER No. 17, p. 14) show that this instrument in its site may be very effective for such research. At any rate, the southern sky is particularly suited for globular cluster studies: it contains more than 100 from the about 140 known galactic globular clusters. Many objects of great interest, as 47 Tuc, the core of which is shown in Fig. 1, are invisible from France.

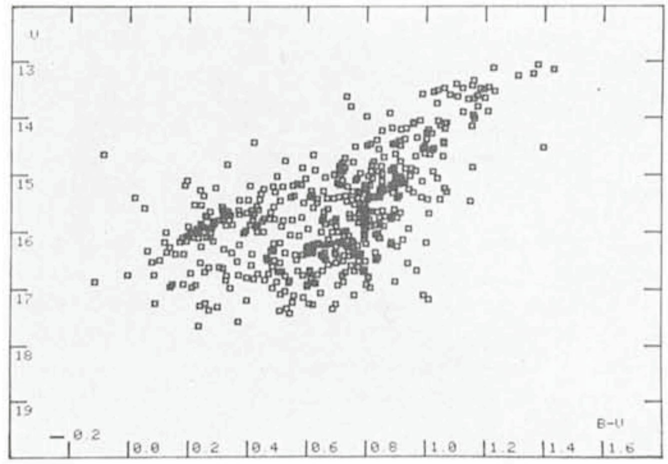

Fig. 2: *Colour-magnitude diagram for 505 stars in a 1′ × 1′ field centred on the northern X-ray globular cluster M 15.*

The Observational Programme and its Aims:

I have used at the 1.5 m Danish telescope at La Silla the instrumentation especially designed for the globular cluster programme at Pic du Midi. It consists of two interchangeable cameras which are placed behind a focal enlarger adjusted to give a focal length of about 35 m (scale of about 6″ per mm). It is known from the experience of planetary observers that a valuable way of securing high spatial resolution images in the case of good seeing is to take a great number of short exposures from which the best ones are selected. The first camera is built around a one-stage image tube. A film holder enables us to take exposures rapidly on 35-mm roll film as with a 35-mm camera. We can obtain in this way unfiltered images of the core of globular clusters with exposure times of a few seconds. These photographs are not suited for photometry but they give the core structure in stars and make it possible to build a map of the star positions. Photometry is made with photographs taken with a B/V camera including a dichroic glass and filters to record pictures in the two passbands in a single exposure. Again, 35-mm roll film is used. These photographs were calibrated at La Silla with the spot sensitometer in the 3.6 m building. Reduction of this material and astrophysical implications of the data are presented in the proceedings of the ESO/ESA workshop on the Space Telescope (Geneva, February 1979), the first colloquium of the "Comité Français pour le Télescope Spatial" (Toulouse, April 1980) and in several papers in *Astronomy and Astrophysics.* Before presenting the data obtained at La Silla, I give some results from the Pic-du-Midi Observatory study to illustrate what one can expect from such studies. Published results concern mainly M15 (NGC 7078), the only X-ray globular cluster of the northern sky, which has an extremely condensed core and, furthermore, presents a central brightness excess over currently observed profiles (King, 1975, IAU Symposium No. 69, p. 99). One part of our work was to carefully study the central condensation associated with the brightness excess. Its brightest point was found to coincide within 1″ with the adopted centre of the cluster: centre of isophotes of faint stars (Leroy et al., 1976, *Astron. Astrophys.,* **53**, 227), equibarycentre of the resolved stars. This is a propitious argument for a theory asking for a massive black hole at the centre of globular clusters, as a consequence of the evolution of the central singularity. This model is able to explain X-ray emission by accretion of gas on the black hole. The brightness of the central condensation in M 15 would be compatible with a black hole of about $10^3 M_\odot$. Other observations however do not confirm this hypothesis. A search for [O III] emission in the core of M 15 (Aurière et al., 1978) has put an upper limit for the intensity of any point source to 1/70 the brightness of the well-known planetary nebula lying at about 30″ from the cluster centre. This result, confirmed by Hα observations (Pic du Midi, unpublished; Philips J. P. et al., 1978, *Astron. Astrophys.,* **70**, 625) infirms previous exciting Hα observations (Peterson A. W., 1976 *Astron. Astrophys.,* **56**, 441; Grindlay et al. *Astrophysical Journal,* 1977, J **216**, L105).

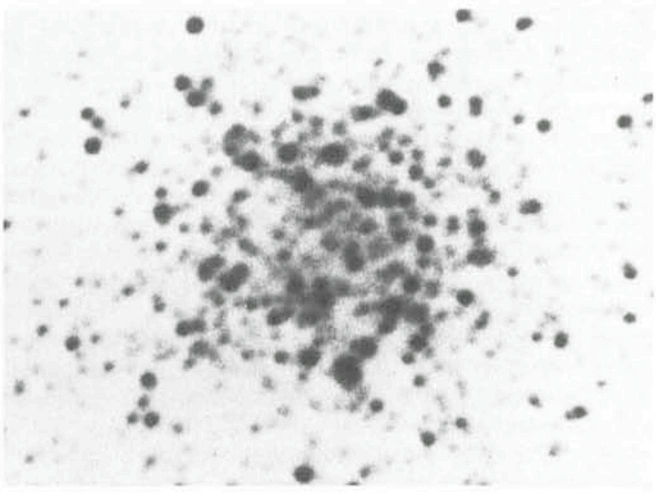

Fig. 1: *The concentrated core of 47 Tuc. North: upper right. Field: 115″ × 80″. 1 sec. unfiltered exposure through the image tube at the 1.5 m Danish telescope.*

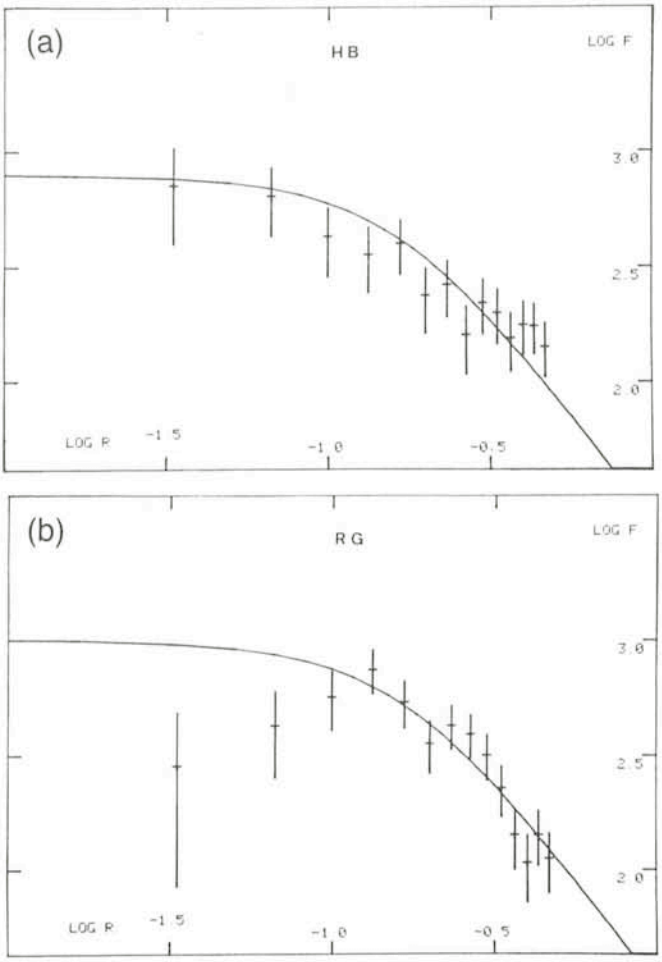

Fig. 3: (a) *(log, log) diagram of the projected density (crosses) for the horizontal branch stars located in the central part of M 15. Crosses are fitted by King's model curves. F: star number by square arcmin. R: distance to cluster in arcmin.* (b) *Same as* (a) *for red giants.*

Pictures with resolution near 0.5″ (taken with the 1 m and 2 m telescopes at Pic-du-Midi Observatory) have enabled us to resolve the central condensation of M 15 into 5 rather faint stellar objects of B-V compatible with common stars of M 15. Spectroscopic observations (Newell B. et al., 1976, *Astrophys. J.*, **208**, L 55; Leroy J.-L., unpublished) confirm that the central condensation in M 15 may not be necessarily composed of exotic objects. As a last observational argument, Einstein X-ray observatory observations have not supported the massive black-hole hypothesis. X-ray sources associated with globular clusters have been found in the cores of these objects but not at their very centre (Grindlay 1980 – Preprint No. 1434 – Center for Astrophysics). In the case of M 15 for which a catalogue of 734 star positions has been obtained (Aurière and Cordoni, 1981, *Astron. Astrophys.* in press) we have been able to locate exactly the X-ray source from Grindlay's position (± 2″). It falls at about 6.5″ from the central condensation in a place without resolved stars. The nearest resolved stars at 1.5″ are two close red giants.

Our photometric data concerning the central part of globular clusters were also used to obtain the B and V magnitudes of individual stars. This is done thanks to a special computing procedure described elsewhere. It enables us to plot the colour-magnitude diagram for stars which are spatially different from those which are generally studied. In the case of M 15 (Fig. 2) we were able to confirm the gaps found by Sandage et al. in the red giant branch (1968, *Astrophys. J.*, **152**, L 129) and to suggest a different slope for this branch. We also used this diagram and the known positions of the corresponding stars to study relative distributions of stars at different stages of evolution and to approach the problem of mass segregation. Dynamical models predict different radial distributions for stars of different masses. Mass loss between red giant and horizontal branches (about 20 % of the initial mass) may give an opportunity to observe the phenomenon. However, this would be observable only in clusters where the relaxation time is less than, or of the order of, the life-time on the horizontal branch. If we suppose this life-time to be about 10^8 years for the stars involved (Caputo et al., 1978, *Monthly Notices of the Royal Astronomical Society,* **184**, 377), the only objects concerned are the central part of concentrated globular clusters. For example, the central relaxation time of M 15 is about 10^8 years, that of NGC 6397 about $2 \cdot 10^7$ years. Fig. 3 illustrates a problem which is encountered when counting the number of evolving stars in a globular cluster core. Their number is small so that statistical fluctuations may mask a possible mass segregation. To elude this problem, we are gathering data for several comparable clusters and will add them.

ESO COUNCIL DECISION

At its last meeting on June 4, 1981, the ESO Council has decided that the title of Dr. A. Ardeberg will be changed from "Astronomical director at La Silla" to "Director at La Silla".

Observations at La Silla

The observing run at La Silla for this programme fell in June 1980. I was not lucky enough to catch excellent seeing in this winter period. The very performant 1.5 m Danish telescope and the adapted instrumentation enabled us to secure several tens of exposures in two nights of effective observation. The spatial resolution of the best short exposures is of about one arc second, which is enough to solve some problems as we will see next. I will present observations made on 3 particular clusters.

The first is 47 Tuc, one of the most famous globular clusters. Fig. 1 shows its core almost completely resolved in its bright stars although it is very concentrated. Fig. 1 is a good complement to classical images showing the whole object but with the central part completely unresolved. The run was only exploratory for this object which was observed far from the meridian. This young cluster (about 10^{10} years) is rather close (at about 5 kpc); it is puzzling because it presents a well-established radial colour variation. Furthermore, from Grindlay's observations with the Einstein Observatory, its core is known to be associated with an X-ray source. We hope that our observations will explain the radial colour variations (in term of variations of the luminosity function of the red giant branch?)

NGC 6397 was one of the main targets of the run: it is one of the two nearest globular clusters, at 2.4 kpc, that is four times nearer than the classical M 3, M 15 . . . famous in the northern sky. This means that observations with 0″.5 seeing, already encountered at La Silla, would place one in a position very near to observing M 3, M 15 . . . with the Space Telescope! Moreover, NGC 6397 has two very important characteristics from the dynamical point of view: it is very old ($17 \cdot 10^9$ years according to Alcaíno and Liller, in Star Cluster, IAU Symposium No. 85, p. 423) and its central relaxation time is small ($2 \cdot 10^7$ years). So

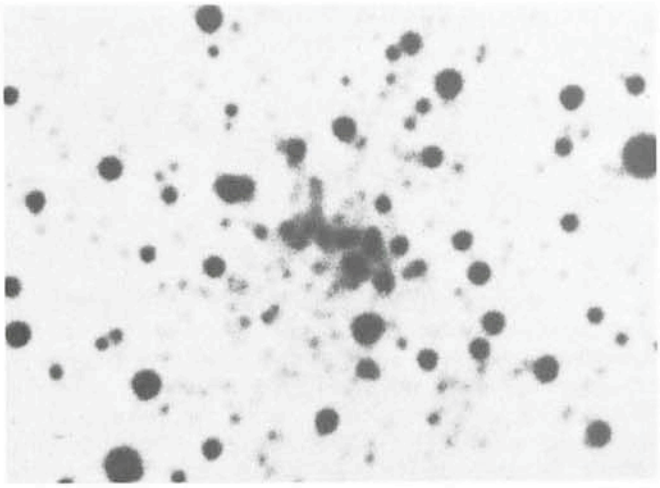

Fig. 4: *The core of NGC 6397 and its central condensation. North: upper right. Field: 85″ × 60″. 8 sec unfiltered exposure through the image tube at the 1.5 m Danish telescope.*

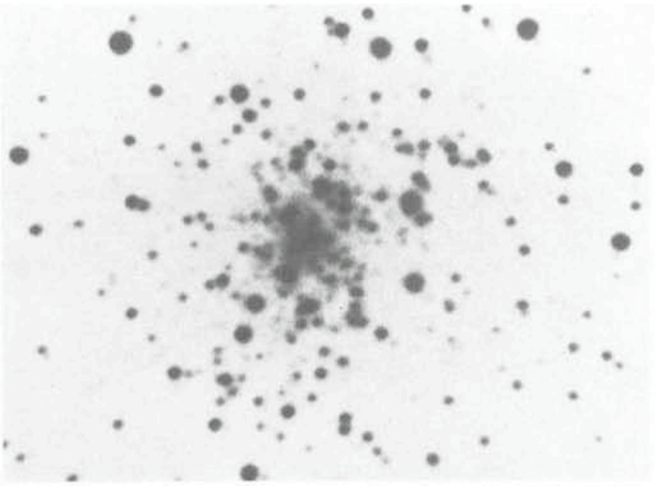

Fig. 5: *The central part of the very condensed core NGC 7099 (M 30). North: upper left. Field 100″ × 70″. 5 sec unfiltered exposure through the image tube at the 1.5 m Danish telescope.*

it is dynamically very advanced and it is a very good case for a possible central singularity. The 1″ resolution photographs of NGC 6397 secured at La Silla are twice as resolvant in parsec as the best ones obtained for M 3 and M 15. In the very centre of the cluster (Fig. 4) we see a condensation of rather faint stars. Radial brightness profiles obtained from the B and V images show that this feature induces a central luminous excess above the isothermal profile. The size of the central condensation is about 10″ or 0.1 pc, which is very near to that of M 15. NGC 6397 seems to be a case of a globular cluster showing a central condensation of rather faint stars. The works of Illingworth and King (1977, *Astrophys. J.*, **218**, L 109) and Heggie (1979, IAU Symposium No. 85), for example, have shown that such central condensations can be explained as the result of collapsed cores. The observational study of these condensations needs high spatial resolution to rule out possible effects of random clumping of bright stars.

M 30 (NGC 7099) was also observed at La Silla. Its declination (about −23°) permits observations from Pic du Midi. It is an example of object that can be observed from the two observatories. Fig. 5 shows one of the short exposures obtained at La Silla which will enable us to work on the B and V photographs obtained from La Silla as well as from Pic du Midi. M 30 is very concentrated and has a central relaxation time of only $1.5 \cdot 10^7$ years. Its core is rather poor in bright stars. We will check if the deficiency in red giants observed in the outer parts is also present in the central part.

Conclusion

A first exploratory observing run at La Silla for studying the core of globular clusters has been fruitful. We have obtained new results and demonstrated that the site is well suited for such research. We plan to have new observations to try to reach still better spatial resolution and to investigate other objects. The investigation will also be extended to Magellanic Cloud globular clusters. If we astutely choose our targets, we might be able to tackle problems which are often believed to be reserved to the Space Telescope.

Visiting Astronomers

(October 1, 1981 – April 1, 1982)

Observing time has now been allocated for period 28 (October 1, 1981 – April 1, 1982). As usual, the demand for telescope time was much greater than the time actually available.

The following list gives the names of the visiting astronomers, by telescope and in chronological order. The complete list, with dates, equipment and programme titles, is available from ESO-Garching.

3.6 m Telescope

Oct. 1981: Azzopardi/Breysacher/Lequeux/Maeder/Westerlund, Véron, M. P. and P., Wlérick/Cayatte/Bouchet, Westerlund, de Graauw/Israel/van de Stadt/Habing, van Dessel/van Paradijs/Burger/de Loore, Seitter/Teuber, Melnick/Terlevich/McMahon, de Ruiter/Zuiderwijk, Pizzichini/Danziger/Grosbøl/Pedersen, Tarenghi, Rosa/D'Odorico, D'Odorico/Baade.

Nov. 1981: D'Odorico/Baade, Hunger/Kudritzki/Simon, D'Odorico/Moorwood, Moorwood/Salinari, Moorwood/Shaver/Salinari, Dennefeld, Thé/Alcaino, Grewing/Schulz-Lüpertz, Wehinger/Gehren/Wyckoff, Macchetto/Perryman/di S. Alighieri, Marano/Braccesi/Zitelli/Zamorani, Valentijn, Wlérick/Cayatte/Bouchet.

Dec. 1981: Wlérick/Cayatte/Bouchet, Lindblad/Athanassoula/Grosbøl/Jörsäter, Grosbøl, Wilson/Ziebell, Rouan, Braz/Lepine/Epchtein, Nguyen-Q-Rieu/Epchtein, Epchtein/Nguyen-Q-Rieu/Braz, Papoular/Epchtein/Le Bertre, Fricke/Kollatschny/Schleicher/Witzel, Schnur, de Ruiter/Lub, Giuricin/Hazard/Mardirossian/Mezzetti/Terlevich, Nelles/Richtler, Miley/Heckman.

Jan. 1982: Miley/Heckman, Pettersson, Thé/Koornneef, Olofsson/Nordh/Fridlund/Koornneef, Eichendorf/Krautter, Krautter/Eichendorf, Eichendorf/Reipurth, van Dessel/van Paradijs/Burger/de Loore, Eichendorf/Reipurth, Danziger/de Ruiter/Kunth/Lub/ Griffith, Gahm/Krautter, Mouchet/Motch/Ilovaisky/Chevalier.