SPACE TELESCOPE OBSERVATIONS OF GLOBULAR CLUSTERS

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ABSTRACT

Six proposed Space Telescope programs involving globular clusters are described. The projects appropriate for galactic clusters are: the detection of white dwarfs, the study of the faint end of the Population II luminosity function, the measurement of mass segregation, and the search for a cusp in the density distribution caused by core collapse or by a massive black hole. The two programs that involve extragalactic globular clusters are: the determination of the luminosity function of clusters around different galaxies and the measurement of tidal radii of clusters surrounding elliptical galaxies.

I. INTRODUCTION

All fields of astronomy will benefit from observations with Space Telescope and the study of globular clusters is no exception. It is easy to be enthusiastic in general about the potentialities of the ST Observatory, but it is more difficult to decide which observations will provide the largest scientific return. I will give my preliminary guesses as to what are some of the most appropriate lines of research for ST observations of globular clusters, but I will look forward to hearing from you - and finally from the observations themselves - as to what really are the most important areas of investigation.

II. CHARACTERISTICS OF THE OBSERVATORY AND THE INSTRUMENTS

I will only review briefly the characteristics of the observatory and the instruments that are most relevant for the present discussion. There are comprehensive discussions in the literature of the telescope and its instruments (see, e.g., O'Dell 1980, Leckrone 1980, Bahcall and Spitzer 1982, and the articles in the Patras session on the Space Telescope Observatory, available from the STScI). As most of you know, the ST mirror is 2.4 m (94 inches), which is not large by ground-based

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standards. The optical design is the Ritchey-Chretien variation of the Cassegrain configuration. The wavelength coverage is broad, from about 1150 angstroms to about 1 micron. The optics is expected to be stupendous. At 6330 angstroms, the full width of a stellar image at half of maximum intensity will be 0.06 arcseconds and 70% of the total image energy will be enclosed within 0.1 arcseconds radius. The actual performance of the mirror may exceed even these wonderful specifications.

There are six instruments in the initial configuration for the Space Telescope Observatory. They are: (1) a Wide Field/Planetary Camera; (2) a Faint Object Camera (supplied by the European Space Agency); (3) a High Speed Photometer; (4) a Faint Object Spectograph; (5) a High Resolution Spectograph; and (6) the Fine Guidance System (which will be used for astrometry). Except for the absence of an infra-red sensitive detector, the initial set of instruments is comparable to the best available instrument complement at a ground-based observatory. For each of the instruments, a number of different modes and options are available. Anyone wishing to know more details should consult one of the review articles cited above.

The characteristics of the instruments determine in large part which projects are most promising for study in the first several years of ST operations. I will therefore limit myself to discussing programs that can be carried out with the existing selection of instruments.

Much of our discussion will center on the use of the two sets of cameras. I will summarize some of the principal characteristics of the cameras. The Wide Field/Planetary Camera (WF/PC) can be used in the following two modes (among others): (1) Field 2.'6 x 2.'6 (f/12.9) and pixel size of 0."1 or (2) Field 1.'1 x 1.'1 (f/30) and pixel size 0."04. The Faint Object Camera (FOC) has many options. The two modes that we consider most often have: (1) Field 0.'4 x 0.'4 (f/48) and pixel size of 0."04 or (2) Field 0.'2 x 0.'2 (f/=96) and pixel size of 0."02. The cameras can reach a visual apparent magnitude $V = 28$ mag in about 30 minutes, with the WF/PC being faster for $\lambda > 5000$ Å and the FOC being faster for $\lambda < 5000$ Å. The cameras will often be used in a novel way: they can simultaneously take exposures on fields whose centers are 6.6 arcminutes apart. This will be especially valuable for extended objects like globular clusters; one can study at the same time a field close to the core and one in the cluster halo.

What are the characteristics of the Space Telescope Observatory that most affect its usefulness for particular kinds of research? The good characteristics are well known: high spatial resolution, broad wavelength coverage, accurate pointing and stability requirements, and high time resolution. The <u>bad characteristics</u> should be equally well known, for they are critical in deciding what should not be attempted. In my opinion, the most limiting features of the ST Observatory are: (1) the telescope is <u>photon starved</u> for many observations (because the aperture is not large); (2) only relatively <u>small fields</u> can be covered in any one exposure (this is not primarily a survey instrument); and (3) ST time will be vastly <u>oversubscribed</u>. This latter characteristic is of special importance. There are only 24 x 365 hours in a year. With an operating efficiency for observations of about 1/3, this means that there are only about 3000 hours available per year for the thousands of astronomers that want to use the telescope. There obviously will not be very many long programs, at least by ground-based standards where a lucky astronomer may hope to get 30 or more nights a year.

III. PREDICTING STAR DENSITIES FOR ST

In order to design some of the Space Telescope projects appropriately, it is necessary to calculate the expected number of stars per unit area that correspond to a total surface brightness that is measured from the ground. This calculation can be carried out conveniently using the conversion function, F:

$$F(\leq M_V) \equiv \frac{\int_{-3}^{M_V} \Phi\ (M_V)dM_V}{\int_{-3}^{\infty} \Phi\ (M_V)L/L_{\odot}dM_V}\ . \tag{1}$$

This function, with different numerical values, was first used by Baum and Schwarzschild (1955) in a different context and, for purposes of predicting ST observations, by I. King (1984). I adopt for the purposes of this talk the Population II luminosity function, $\Phi(M_V)$, used by Bahcall and Soneira (1984). At the bright end, this luminosity function is the same as the 47 Tuc luminosity function of Da Costa (1982). The adopted luminosity function, when combined with the Bahcall-Soneira Galaxy model, also fits the observed counts of spheroid field stars. The available counts are mainly sensitive to the region $M_V = +3$ to $M_V = +8$. The luminosity function used here includes both an estimate for the effect of the horizontal branch and the Wielen dip, near $M_V = 6$. The luminosity function and the contribution to the luminosity from different absolute magnitudes (the integrand of the integral in the denominator of equation 1) are shown in Figure 1.

Table 1 gives some numerical values for the conversion function, $F(\leq M_V)$. The number of stars expected per unit of area to a given absolute magnitude can be calculated from the observed surface brightness, σ (in stars per square arc second or stars per square arc minute), the estimated distance modulus $(m - M_V)$, and the conversion function F. One has:

$$N(\leq M_V) = F(\leq M_V) \times 10^{-0.4[\sigma - (m - M)_V - 4.7]}. \tag{2}$$

For several of the projects that we will discuss below, it is important to know at what star density the effects of crowding will become significant. A reasonable criterion can be established in analogy with ground-based experience, which is summarized in the classic article of King, Hedemann, Hodge, and White (1968). For purposes of this discussion, we can anticipate that crowding will become significant when the area on a detector that is covered by star images reaches about 3%.

This criterion suggests that the interpretation of star densities of more than about 3 per square arc second in the visual wavelengths will be complicated by crowding effects. It is possible that the optical properties of the mirror will be considerably better in the ultraviolet, although we will not know the ultraviolet characteristics until they are measured when the telescope is operating in space.

For deep exposures, the condition for crowding to be significant can be expressed, using Table 1 and equation (2), as

$$10^{-04[\sigma_V(r) - (m - M)_V - 4.7]} \leq 3/F(\leq M_V),$$

when σ is expressed in magnitudes per square arc second.

IV. SOME IMPORTANT GALACTIC ST PROGRAMS

I will now discuss four illustrative galactic programs that seem to me to be both particularly important and especially appropriate for ST observations.

A. The Detection of White Dwarfs

The study of white dwarfs in globular clusters is a "made-for-ST" project! Even the youngest of the white dwarfs are expected to have $M_V = +10$. Therefore their apparent magnitudes are $V \approx 24$ or fainter in the clusters - difficult to detect with ground-based telescopes. On the other hand, the apparent visual magnitude range between 24 and 28 is convenient for observations with both cameras on the ST. Moreover, calculations suggest (see below) that a number of white dwarfs should be visible on a single FOC frame (f/48) of the inner regions of nearby globular clusters.

The study of the number of white dwarfs in globular clusters will be important for the theory of stellar evolution since it will be possible to check the general expectation that stars with masses less than a critical mass (variously estimated between $3M_\odot$ and $10M_\odot$) end up as white dwarfs. Moreover, it will be possible to study the cooling of white dwarfs in a much simpler context than can be done with disk stars: all of the objects are at the same distance and the only variation in the time of the formation of the white dwarfs is caused by the stellar evolution time of the parent. This study is especially important since there is a well known discrepancy between the theory of white dwarf cooling and the observations of disk white dwarfs.

There are two physical effects that must be taken into account in order to predict the expected number of white dwarfs in globular clusters. (1) The total number of white dwarfs that are created depends upon the initial mass function of the globular cluster. (2) The white dwarfs formed by the more massive stars will already have cooled down to fainter magnitudes. One can express, symbolically, the expected number of white dwarfs per unit area, N_{WD}, in terms of the total number of stars, N, given in equation (2). One has,

$$N_{WD} = G_{cool}(\leq M_V) \times R \times [F(M_{V,turnoff}) - F(M_{V,critical})]$$

$$\times\ 10^{-0.4[\sigma - (m - M)_V - 4.7]}. \qquad (3)$$

The function G_{cool} represents the fraction of the white dwarfs that have not cooled down below M_V. R is the average amount by which the initial mass function exceeds the Population II luminosity function used to calculate the conversion function, F. Assuming a Salpeter (1955) initial mass function, a critical mass for the production of white dwarfs of $5M_\odot$, and a turnoff mass of $0.7M_\odot$, I find: $R \approx 6$.

Only those white dwarfs that have formed relatively recently, from masses just above the turnoff mass, will still be bright enough to be detected with ST. I have estimated G by using the fact (see VandenBerg 1983) that the turnoff luminosity is approximately proportional to the inverse age of the cluster and to the fourth power of the turnoff mass. This implies that the ratio of the range of masses from which observable white dwarfs have come to the present day turnoff mass is about

$$\frac{t_{cool}}{4t_{age}},$$

where t_{cool} is the time for white dwarfs to cool down to the limit of detectability and t_{age} is the age of the cluster. Carrying out the integrals over a Salpeter initial mass function, I find:

$$G_{cool}(\leq M_V) = \frac{0.35 \times t_{cool}}{t_{age}}. \qquad (4)$$

The quantity G is very small and greatly reduces the expected number of detectable white dwarfs. For example, one might expect to be able to study white dwarfs down to absolute visual magnitudes of about 13.5 (or with a major effect perhaps to 14.5) in the nearer clusters. Using the white dwarf cooling times of Lamb and van Horn (1975) scaled to $0.7M_\odot$ as given in equation (7) of Green (1980), I find that

$$\frac{t_{cool}}{t_{age}} \approx 0.1\ (0.2). \qquad (5)$$

Thus G is only of order 0.035 for $M_V \leq 13.5$ and rises to 0.07 for $M_V \leq 14.5$. For the more distant clusters, we may be able to reach to $M_V = 12.5$, in which case G decreases to 0.015. More generally, $G(\leq M_V) \cong 0.035 \times 10^{0.3(M_V - 13)}$.

I have estimated for the high surface brightness cluster 47 Tuc the number of white dwarfs that may be visible in a deep exposure (1/2 hour) with the FOC (f/48 mode) to U = 27 mag and V = 27 mag. For 47 Tuc, I took (Peterson and King 1975) a distance modulus of 13.5, a central surface brightness in the visual of 5.55 magnitudes per square arc minute, and a core radius of 0.7 pc. In order to avoid crowding effects, I assumed that the part of the frame that was closest to the center was at a radial distance of three core radii. I also averaged the predicted surface density over the surface of the FOC detector, assuming that the cluster is described by a King profile.

The net result of these calculations is that only of order 15 white dwarfs are expected to be visible on the FOC frame of 47 Tuc. This is about 1% of the total number of stars that are expected to be detected in the FOC exposures discussed above.

I have made a similar set of calculations for M4 which has a much lower central surface brightness (about 9.15 mag per square arc minute), and is closer than 47 Tuc (2.1 kpc compared to 4.9 kpc). In this case, one can center the exposure on the core of the cluster. Assuming the same limiting magnitudes of U = 27 and V = 27, I find that only of order 5 white dwarfs are expected in a single FOC (f/48) frame of M4.

B. The Low Mass Stars

The detection of the faint end of the globular cluster luminosity function is of great theoretical interest because of the light it may shed on the dynamics of globular clusters and on theories of star formation. Are the low mass stars concentrated on the outside of the clusters? Have they been stripped from the outermost regions? What is the spectrum of stellar masses that were formed? Since all of the stars are at the same (known) distance as the parent globular cluster, some aspects of this study will be simpler than for the corresponding investigations with disk stars. Moreover, it is possible that the study of the faint end of the cluster luminosity function will provide some clue as to whether or not the so far unobserved mass in the disk could be in the form of low mass stars.

I have calculated the expected number of stars that will be observed in an exposure to V = 27 mag if the Pop II luminosity function shown in Figure 1 is appropriate to the clusters. In order to verify that stars are indeed of low mass, it will be necessary to take also a deep exposure in I with the wide field camera. For 47 Tuc, the total number of stars is about 10^4 in a frame situated as described above. For a central exposure on M4, the corresponding number is also about 10^4. About one-fourth of these stars may have masses between $0.1M_\odot$ and $0.3M_\odot$, if the stars were originally present and dynamical effects have not depleted the core of low mass stars.

C. Mass Segregation

The effects of mass segregation can be studied with ST observations over a wide range of masses, from the turnoff mass ($\approx 0.7M_\odot$) to the mass corresponding to the faintest limiting magnitude ($\approx 0.15M_\odot$ for the nearest clusters).[1] This range corresponds to a ratio of masses of more

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[1] In the absence of an empirical mass to visual light relation for low mass Population II stars, I have interpolated between the low-metallicity and normal metallicity parameters at a given effective temperature in the theoretical study of VandenBerg et al. (1983). I normalized the results to the empirical mass versus visual luminosity relation for normal metallicity disk stars.

than four. Observations with the cameras should yield star surface densities over a very large range in radii also, from $\approx 0 \times r_{core}$ to more than $25 \times r_{core}$. These data can be acquired as a natural by-product of the programs to detect white dwarfs and low mass stars. It will be particularly useful to take simultaneous exposures with the WF/PC and the FOC, one close to the cluster center and one quite far away (6.6 arc minutes or of order 20 core radii for some typical cases).

Multi-mass models for clusters should become the norm, not the exception, for both analytic studies and for many-body simulations. The beautiful data of Da Costa (1982) already show that mass segregation is an observationally accessible and important phenomenon in 47 Tuc. In addition, various theoretical studies that were discussed at this conference have confirmed the importance of mass segregation. This topic will become even more lively when ST observations are available over a large range of masses and radial distances for many different clusters.

D. Core Collapse/Massive Black Hole

As we have heard at this conference, the dynamical evolution of globular clusters is expected to lead to a strong density enhancement in their centers. The expected density profile has been calculated in two limiting cases: 1) the cluster undergoes "core collapse" (see, e.g., the references in Heggie's talk at this conference, in the recent discussion by Cohn and Hut 1984 and in Lightman and Shapiro 1978); and 2) the core contains a massive black hole (see the informative and clear summary of this subject in S. Shapiro's talk at this conference). The predictions that are made from these two scenarios are similar. I shall discuss the expectations for a density cusp using the language appropriate to a massive black hole because the details of the predictions have been worked out for this case - including the effects of mass segregation and the interactions with unbound stars.

In the presence of a massive black hole, the stellar distribution function in the central region of the cluster has the form (Bahcall and Wolf 1976, hereafter Paper I)

$$f(E) \propto E^{1/4}; \qquad n(r) \propto r^{-7/4}. \tag{6a}$$

The square, R, of the ratio of the velocity dispersion of the bound stars to the unbound stars is (equation 94 of Paper I):

$$R = \frac{4}{11}\left(\frac{r_h}{r}\right), \tag{6b}$$

where

$$r_h = \frac{GM_{BH}}{(\text{LOS velocity dispersion})^2}$$

is the characteristic radius over which the black hole perturbs the star distribution (Peebles 1972). Equation (6) is correct when:

1) all the stars have the same mass; 2) the boundary conditions are ignored; 3) large angle collisions are neglected; 4) the loss cone is ignored; and 5) binaries are unimportant. The Boltzmann equation can be solved numerically (Paper I and Bahcall and Wolf 1977, hereafter Paper II) when all of these effects are included.[2] The only effect that alters significantly the density distribution (but see below) is the mass spectrum. If, for example, there are two classes of stars with masses M_1 and M_2, then the distribution functions of the bound stars are of the form (Paper II):

$$f_i(E) \propto E^{p_i(E)}\ ; \qquad n_i(r) \propto r^{-(3/2\,+\,p)}. \tag{7a}$$

The cusp exponents satisfy a symmetry relation:

$$\frac{1}{M_1}\, p_{M_i} = \frac{1}{M_2}\, p_{M_2}. \tag{7b}$$

The numerical solutions show that the larger mass always has (an approximately constant) cusp coefficient $p_{\text{more massive}} = 0.31$. For $M_1 = 4M_2$, corresponding to an extreme range of masses for globular clusters, $p_1 \approx 0.31$ and $p_2 \approx 0.078$.

The sensitivity of observational tests to the presence of a massive black hole scales approximately as

$$\frac{M_{BH}}{(\text{LOS velocity dispersion})^{3.5}\, r_{\text{core}}}\ .$$

Ground-based measurements of the line-of-sight velocity dispersions are needed for many of the nearby clusters in order to predict what one might be able to see with Space Telescope and to interpret future ST observations.

For illustrative purposes, I have chosen parameters that are appropriate to 47 Tuc (see Illingworth 1976), a core radius of 0.7 pc and a line of sight velocity dispersion of 10.5 km s^{-1}. This cluster is not a particularly likely candidate for harboring a black hole, but at least Illingworth has measured the relevant structural parameters.

Figure 2a compares the surface brightness of equal mass stars in the presence of a black hole with mass $M_{BH} = 5 \times 10^3 M_\odot$ with the distribution expected in the absence of a black hole. [The results shown here and in Figure 2b and 2c are based upon equation 88 of Paper II.]

I show in Figure 2b the projected number densities of stars that would be observed near the center of 47 Tuc if it contains a massive black hole (the dark circles) of projected mass $5 \times 10^3 M_\odot$. The open triangles represent a King model in the absence of any massive singularity at the center. The error bars are estimates of what may be obtainable with the Space Telescope using star counts (here assumed to

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[2] Lightman and Shapiro 1977 have given an elegant discussion of the effect of the loss cone.

be a maximum of 10 stars in the inner one arc second). One can infer from Figure 2b that, even in unfavorable cases such as 47 Tuc it may still be possible to detect black holes with masses as large as $5 \times 10^3 M_\odot$ and, perhaps in more favorable cases, (with smaller velocity dispersions and core radii, see scaling relation quoted above) $10^3 M_\odot$.

A comparison of Figures 2a and 2b suggests that surface brightness measurements may be a more powerful diagnostic than star counts. This inference is correct provided that the star counts cannot go very deep in the central region because of crowding effects (see the detailed comparison of star counts versus surface brightness measurements in section VId of Paper II) and provided one can prevent the bright stars from dominating the light. One can bias against the bright red giants by using ultraviolet exposures.

Figure 2c compares the distributions predicted for two stellar populations when $M_1 = 4M_2[n_1(r) \propto r^{-1.81};\ n_2(r) \propto r^{-1.58}]$. It does not seem feasible to detect even this substantial difference in the density laws of the two stellar populations within the core of a globular cluster. Unfortunately, this conclusion implies that it will not be easy to distinguish observationally between core collapse and massive black hole solutions, since the difference between two such dynamical explanations is probably only of order 0.3 in the cusp exponent. The effect of a loss cone is even more difficult to detect since it changes the cusp exponent by less than 0.02 (Bahcall and Wolf 1977), an order of magnitude less than the unobservable difference shown in Figure 2c.

I conclude that it may be possible in favorable cases to detect, by measurements of the surface brightness or by star counts, a density enhancement of order $10^3 M_\odot$, but it will probably not be feasible to determine many theoretically interesting details of this density distribution.

Complementary information can be obtained by measuring the central velocity dispersion and line profiles (see Vb of Paper I).

V. TWO IMPORTANT EXTRAGALACTIC ST PROGRAMS

I will discuss next two important ST programs that can be carried out on extragalactic globular clusters.

A. The Luminosity Function of Globular Clusters

The measurement of the luminosity function of globular clusters is another "made-for-ST" project! Ground-based observations suggest (see Hanes 1977 and Harris and Racine 1979) that the relative number of globular clusters per unit of luminosity is a universal (perhaps Gaussian) function, which may have a peak near $M_V = -7.3$. If correct, this conjecture would imply that the globular cluster luminosity function of Virgo galaxies would have a peak near V = 23.5 mag, implying that the declining part of the luminosity function would be just beyond the ability of ground-based telescopes to carry out reliable observations.

If the luminosity function does indeed have a characteristic shape that permits a well-defined luminosity calibration, then it will be possible to carry out an "all ST, Population II" determination of the Hubble constant. Direct parallax measurements of RR Lyrae field stars in the Galaxy can be carried out with the astrometric capability of the fine guidance system and will allow a direct calibration of the intrinsic luminosities of the RR Lyraes and hence the distances and luminosities of the galactic globular clusters.

How many globular clusters are expected in a single WF field centered near a prominent galaxy in the Virgo cluster? I have calculated the number of clusters that are expected to be detected in frames that begin 2 arc minutes (≈ 9 kpc, in order to avoid confusion) from particular galaxies of interest. The results are shown in Table 2 and indicate that of order 50 to 100 globular clusters should be detectable for the more luminous galaxies. The principal uncertainty in these predictions - assuming that the form of the luminosity function is exactly Guassian - is the uncertainty in the plate limit of the ground-based observations (which is known in some of the best cases to only about ± 0.5 mag; see, e.g., Harris and Petrie 1978).

Observations should be carried out on a variety of galaxies to determine to what extent the shape of the globular clusters luminosity function is dependent on galaxy morphology or luminosity. In order to provide some indication of what is required in order to relate the Virgo observations directly to the globular cluster population of the Galaxy, I have calculated the number of globular clusters that would be visible on a WF frame if the Galaxy with its 180 globular clusters (Harris and Racine 1979) were moved to Virgo. I find that only 5 clusters would be visible on a frame that began 2 arc minutes (9 kpc) from the Galaxy's center. If the Galaxy happened to be seen edge-on so that observations as close as 1 effective spheroid radius (2.7 kpc) were possible, the number of clusters would be about 16 on a WF frame.

The main background in these measurements will be field galaxies. Figure 3 shows a simulation of what the WF/PC is expected to see in a typical deep exposure at high galactic latitude. About 50 galaxies are expected in each of the four quadrants of the WF/PC. These galaxies must be separated from the program globular clusters by their colors and by the lack of concentration to the center of the program galaxy (as determined by the number density from serendipidous exposures in similar areas of the sky).

B. Tidal Radii of Clusters Around Elliptical Galaxies

K. Freeman (1979) pointed out the importance of measuring with ST the tidal radii of globular clusters around distant elliptical galaxies. The mass of the galaxy, M_{galaxy}, contained within a given distance D is proportional to the cube of the cluster tidal radius, i.e.,

$$M_{galaxy} \approx (D/r_{tidal})^3 M_{cluster}.$$

The expected tidal radii are about 1 arc second at the distance of the Virgo cluster for a globular cluster located 10 kpc from the galactic center. Thus one should be able to measure the tidal radii of clusters all the way out to the Virgo cluster and perhaps a little beyond. This measurement will be one of the few reliable ways of determining the potential field and mass of elliptical galaxies. The recent demonstration by Elson and Freeman (1984) that the mass for the LMC cluster NGC 1835 that is inferred from measurements of the velocity dispersion and from the tidal radius is the same to within a factor of two strengthens confidence in the method.

VI. SUMMARY

There are many important globular cluster programs that can be done with Space Telescope. I have mentioned only a few that are of special interest to me. Undoubtedly, you can think of a number of other projects that ought to be carried out (see the excellent review by Freeman 1979 for different suggestions). The limitation will not be the lack of good ideas, but the small amount of observing time that is available.

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TABLE 1. The Conversion Function, F. The function F(M_V) converts surface brightness per unit area to star counts per unit area using a Population II luminosity function (from Bahcall and Soneira 1984).

M_V	F	M_V	F
-2.0	3.3 E-5	7.0	3.0 E-1
-1.0	6.0 E-4	8.0	3.9 E-1
-0.5	1.2 E-3	9.0	5.0 E-1
0.0	2.1 E-3	10.0	6.6 E-1
0.5	3.8 E-3	11.0	9.0 E-1
1.0	9.7 E-3	12.0	1.2
2.0	1.4 E-2	13.0	1.7
3.0	1.9 E-2	13.5	1.9
4.0	4.0 E-2	14.0	2.2
5.0	1.1 E-1	15.0	2.6
6.0	2.1 E-1	16.5	3.2

TABLE 2. The Expected Number of Globular Clusters in a WF/PC Field to V = 27 mag for Virgo Galaxies. The exposures reach to within 2 arcmin (9 kpc) of the galaxy centers.

Galaxy	Type	Number of Clusters
NGC 4486	E0	$10^{2.5}$
NGC 4374	E1	$10^{1.9}$
NGC 4472	E2	$10^{2.1}$
NGC 4526	S0	$10^{2.0}$

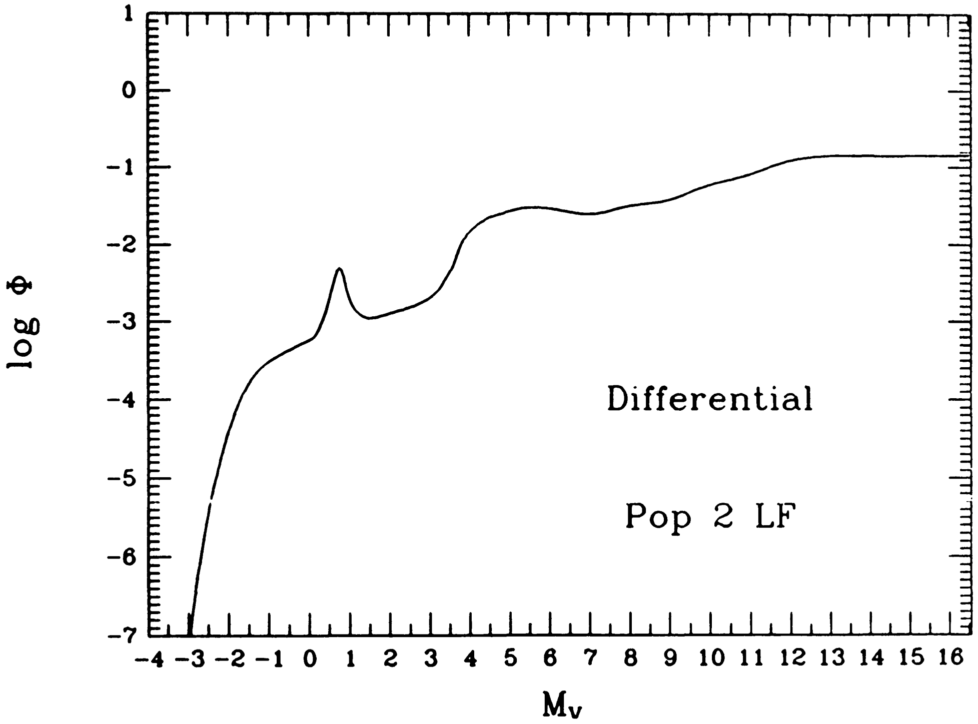

Figure 1a. The Population II luminosity function used by Bahcall and Soneira (1984). The bright end of the luminosity function is the same as the 47 Tuc luminosity function used by Da Costa (1982). The luminosity function fits the spheroid field counts in the observable region between $M_V = +3$ and $M_V = +8$.

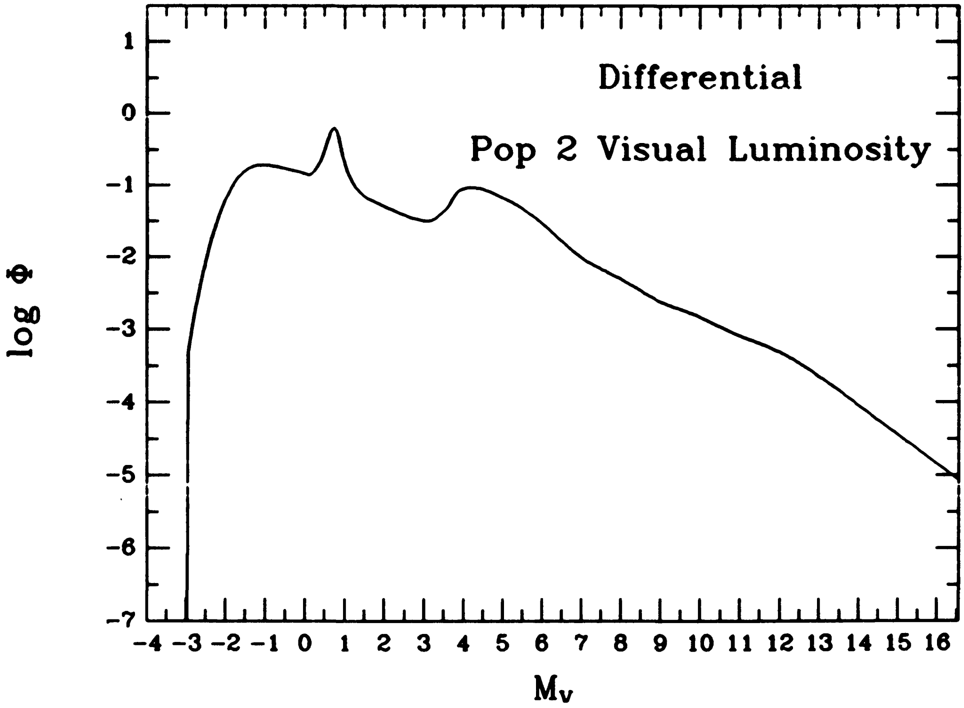

Figure 1b. The contribution to the luminosity from different absolute magnitudes for the luminosity function shown in Figure 1a.

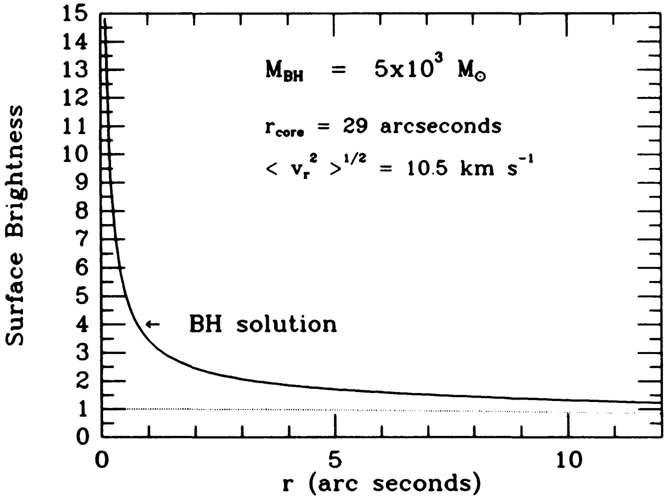

Figure 2a. The surface brightness as a function of projected distance from the center of a globular cluster in the presence of a massive black hole, $M_{BH} = 5 \times 10^3 M_\odot$. The stars are assumed to all have equal masses. The parameters for the cluster are taken from Illingworth's (1976) study of 47 Tuc. The dotted line is a King model in the absence of a central singularity.

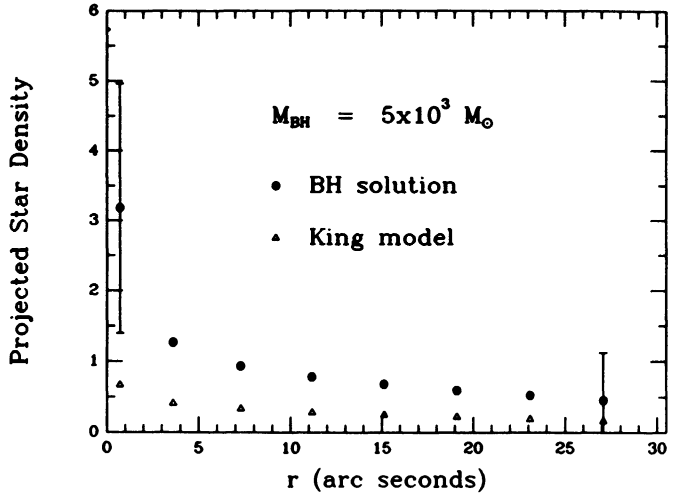

Figure 2b. Star counts as a function of projected distance. Otherwise, the same as for figure 2a.

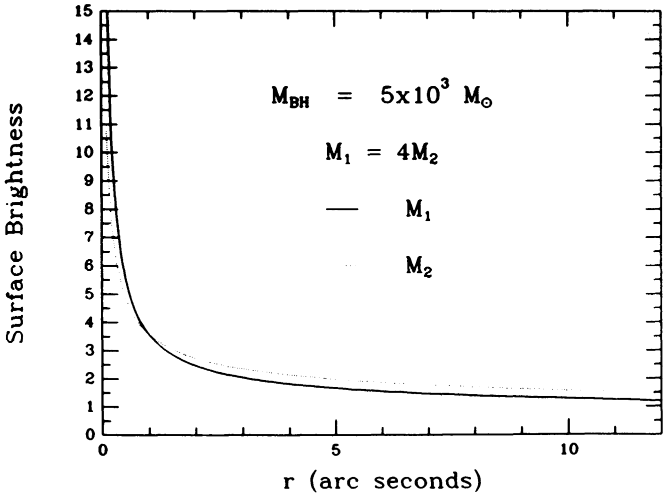

Figure 2c. Surface brightness as a function of radius for stars with two different masses, $M_1 = 4M_2$. Otherwise, the same as Figure 2a.

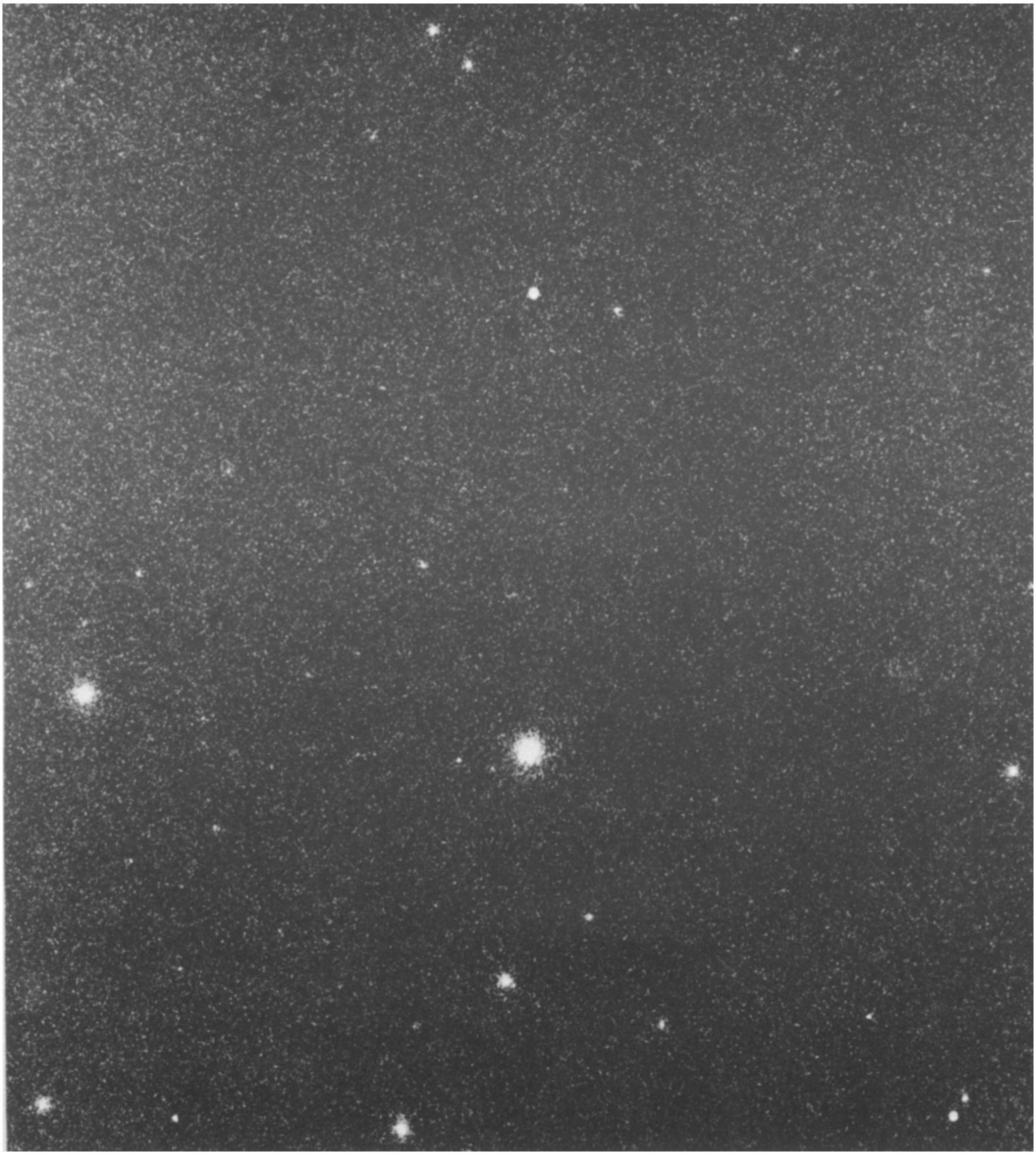

Figure 3. Simulated WF/PC V-band picture with Space Telescope. The simulation [J. Bahcall and R. Soneira, 1979, for the STWG] refers to one quadrant of a WF/PC field at a high galactic latitude. A Hubble constant of H_0 = 50 km $s^{-1^{-1}}$ with q_0 = 0.1 and Tinoley x = 2 evolution is assumed. The exposure reaches to V = 28 mag with a signal/noise ratio of 3.
There are 6 stars and 51 galaxies in this field which is 1.3 arc min. on a side.

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DISCUSSION

COHN: I would like to note that the difference between the slopes of the radial density profiles for components of different mass is much larger in the case of simple core collapse (with no black hole) than in the case of a black hole cusp. This may provide another observational means of distinguishing between these two alternatives.

BAHCALL: Good point. But I am not optimistic.

KING: With regard to the brightness distribution at the center of 47 Tucanae, I believe that published data of Djorgovski and me (Ap.J. Letters 277, 49, 1984) already exclude a central brightness peak.

BAHCALL: It's a matter of resolution. You can always have an unresolved peak if the central mass concentration is not too large. In any event, I only used 47 Tuc as an illustration, not a likely case.

FALL: There are good dynamical reasons for thinking that the luminosity function of globular clusters should differ from one galaxy to another. Given that, is it not more likely that we will learn from ST observations about the presence or absences of such variations rather than obtaining an independent distance-scale?

BAHCALL: You could be right. We will see. I wouldn't want to bet on what we will learn until the observations are made and the analysis is complete.