MCAO Science Cases for Nearby Galaxies: Probing the Early Stages of Galaxy Formation

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1 INTRODUCTION

Nearby galaxies are unique in that they can be resolved into individual stars, and hence these objects provide a fundamental stepping stone for understanding the properties of more distant systems. The stellar contents of Local Group systems have been resolved for over 50 years, starting with the pioneering work of Baade. However, it is only recently, using ground-based telescopes that exploit the best sites, such as the CFHT, and space-based facilities, such as the HST, that it has been possible to study individual stars in galaxies outside the Local Group, with the result that objects covering a diverse range of morphologies and environments are sampled. The ability to resolve stars in the Virgo cluster is of particular importance, as this is the nearest large cluster, and as such provides an unprecedented laboratory for understanding clusters at larger redshifts.

At present, efforts to resolve galaxies are limited by aperture size, which restricts efforts to gather large numbers of photons from faint sources, and image quality (e.g. Bedding, Minniti, Courbin, & Sams 1997, A&A, 326, 936). Because of their large collecting area and emphasis on achieving near diffraction-limited image quality, the 8-m Gemini telscopes have the potential of opening new frontiers in the study of nearby galaxies.

Studies of stars in nearby galaxies require wide-field surveys to obtain statistically significant samples and probe changes in stellar properties that may occur due to, for example, age and/or metallicity gradients. The characteristic angular dimensions of nearby systems are summarized in Table 1. The dimensions of these structures exceed the isoplanatic patch sizes delivered by traditional single-star adaptive optics systems, which typically are a few tens of arcsec.

Table 1

Structure	Angular size
Galactic globular cluster ½ light radius	30 - 180 arcsec
Bulge scale length (Virgo)	5 - 30 arcsec
Disk scale length (Virgo)	50 - 300 arcsec
Scale length (Virgo E)	40 arcsec

Because of a potential improvement in field size, multiconjugate adaptive optics (MCAO) systems on 8-m telescopes may offer an unprecendented means of studying nearby galaxies. In an effort to demonstrate the scientific potential of an MCAO system on Gemini, we have defined a number of sample science programs. The intent is not to assemble an exhaustive list of science targets; rather, it is to examine a small number of science programs that consider targets ranging from the Milky-Way to distances in excess of 10 Mpc. These programs share a common theme, which is to probe the critical formation events in galaxies, when basic structural properties were imprinted. The ultimate goal is to distill a set of common requirements for these programs, which in turn will serve as the basis for detailed numerical simulations.

AO systems deliver diffraction-limited performance at near-infrared wavelengths, and this wavelength bias is reflected in the science programs. The near-infrared is a critical portion of the spectrum for studying old and intermediate-age populations, as the coolest, most evolved stars in these systems, while being relatively faint in the visible part of the spectrum, reach their peak brightnesses at wavelengths longward of 1 micron. The near-infrared is also of paramount importance for probing heavily obscured star forming regions in nearby galaxies. Finally, the near-infrared is a logical portion of the spectrum for studying the lowest mass stars in the Galaxy, which have temperatures that place the peak of their spectral-energy distributions between 1 and 2.5 microns, along with strong absorption features that are temperature diagnostics.

2 SAMPLE SCIENCE PROGRAMS

2.1 The Faintest Objects in Old Stellar Systems (Dante Minniti)

2.1.1 The Deepest and Sharpest Images of Old Galactic Populations

Much of our understanding about the early stages of galaxy formation and conditions in the early Universe comes from the study of nearby old stellar populations. The oldest stars in the Milky Way are located in globular clusters and the Galactic bulge (van den Bergh 1994). With Gemini+MCAO it will for the first time be possible to obtain diffraction-limited H and K images of selected large fields in the Milky Way bulge and globular clusters with angular resolutions surpassing 0.1 arcsec. Data of this nature can be used to investigate:

1. The old stellar content of the Galaxy,
2. The faint end of the luminosity and mass functions, and
3. The rate of planet formation in old populations as a function of metallicity.

Photometry of point sources as faint as H=24 with $\sigma_H \sim 5\%$, when combined with existing deep HST optical images, (e.g. the deepest bulge HST color-magnitude diagrams by Holtzman et al. 1998, AJ 115, 1946), will allow colour-magnitude diagrams of old populations to be constructed that reach 6 magnitudes below the main sequence turn off.

Theoretical models predict that 0.050 $M_\odot$ dwarfs will have M_H=10, which corresponds to H=24.5 for the bulge, and H < 23.5 for the nearest globular clusters, so deep MCAO images will allow the brown dwarf regime to be probed in these systems. These data will thus constrain the mass function in the regime required to understand the population of MACHOS that give rise to microlensing events in the bulge (Alcock et al. 1999, ApJS, 124, 171).

The positions of point sources accurate to 1/10th of a pixel (0.002 arcsec) will also be obtained from these images, and these data will serve as the first epoch for proper motions studies. With a baseline of about 5 years, accurate tangential velocities of these target stars will be obtained, unveiling the dynamics of old stellar systems.

2.1.2 Extrasolar Planet Hunting Using Continuous Monitoring

The radial velocity technique has proven to be a highly successful means of discovering extrasolar planets, especially massive planets on short period orbits; for example, the famous early discoveries of 51 Peg and υ And by Mayor & Queloz (1995) and Marcy & Butler (1996) found giant planets with periods P ~ 4^d. There are now about 10 such 51 Peg *b*-type planets that have been detected with radial velocity searches. The success of this technique has spurred other approaches, such as microlensing (e.g. Bennett et al. 1997, ASP Conf. 119, 65), and planetary transits (Schneider 2000, "The Extrasolar Planet Encyclopedia", http://www.obspm.fr/planets). Transit events are of particular interest, because the orbit and size of the planet can be calculated from the period and depth of the transits. There are now different collaborations conducting searches for transits, with the first confirmed success being the P=3.5^d planet around HD 209458 (Charbonneau, Brown, Latham & Mayor 2000, ApJ, 529, L45). However, these surveys are restricted to systems in the disk (e.g. nearby main-sequence stars, open clusters, and low-galactic latitude fields) at visible wavelengths. A thorough planet search yielding a complete census of 51 Peg *b*-type planets in old populations of stars is needed, as this will allow astronomers to confront theoretical predictions of planet formation with direct observations.

Since the depth of the planetary transits goes as R_p^2/R_*^2, in order to detect transits one must repeatedly observe large numbers of small (R < 0.5 $R_\odot$) stars on short timescales with accurate relative photometry. While this is challenging, it is not impossible, because Gemini+MCAO would allow the rapid collection of photons for > 10000 stars in the target fields, and only differential measurements are needed.

2.1.3 The End Product of the Gemini+MCAO Observations

Data obtained with an MCAO system on Gemini will produce an unprecedented multi-color dataset of moderately large fields in the bulge and globular clusters, with temporal coverage if multi-epoch images are recorded. The coadded exposure time of 90 minutes in the H band would reach about H=23.5 with S/N=10, and will largely surpass the deepest maps made to date with HST data. The end products of these observations are of immense archival value for the Gemini community, and would lead to many other scientific applications, such as:

1. Deep color-magnitude diagrams to define the bottom of the main-sequence.
2. Deep mass functions down to the brown dwarf regime.
3. A short period eclipsing binary census encompassing the lowest mass stars.
4. A definitive assessment of background contamination through color-color diagrams.
5. The measurement of accurate tangential velocities, which in turn allow a direct means of searching for mass segregation and other dynamical effects.
6. Intrinsic stellar variability studies.
7. Providing the basis for follow-up studies by other groups, such as probing planetary atmospheres during transits or obtaining high-precision radial velocities.

2.1.4 Program Summary

Intrinsic brightnesses of target sources:

$M_K = 3$ (main sequence turn-off of an old population), $M_K = 10$ (approximate brightness of the bottom of the main sequence)

Observables:

Deep J H K images, with 20-sigma accuracy at H = 23.5, obtained over time periods of days (transit searches) to years (proper motion studies).

Sample targets:

- The Milky Way bulge (m-M = 14.5).
- Nearby globular clusters with D=2-5 kpc (m-M < 13.5), covering a wide range in metallicity (e.g. M4, M22, M71)

Observing requirements:

- diffraction limited imaging in 1 - 2.5 micron wavelength interval.
- stable psf over a field of view of order 1 arcmin^2, with the intent of observing over 10000 stars per field.
- diffraction-limited performance (i.e. moderately high Strehl ratios) to identify the background galaxy population that dominates at faint magnitudes.

Key Diagnostics:

- (K, J-K) CMDs to characterize the stars.
- (J-H, H-K) two-color diagrams to identify background contaminants.
- H light curves to detect planetary occultations.
- multi-epoch astrometry for proper motion studies (the time baseline is on the order of years, so the instrument must be stable for this period of time).

2.2 The Early Chemical Enrichment Histories of Nearby (r < 10 Mpc) Galaxy Spheroids (Tim Davidge)

The traditional view of galaxy formation is that spheroids, which here refers not only to elliptical galaxies, but also to the halo + bulge components of disk systems, formed during early epochs as the result of a rapid, dissipative, collapse. However, there is growing evidence that this picture is overly simplistic, and that hierarchal merging plays a key role in spheroid evolution, especially in low density environments. A further complication for bulges is that gas from the surrounding disk may be driven into the central regions of the galaxy, thereby triggering episodes of star formation well after basic morphological properties (e.g. M_B, ellipiticity, bulge to disk ratio etc) were imprinted. The metallicity distribution function (MDF), which is the histogram distribution of stellar metallicities, is a key diagnostic for probing the collapse history of galaxies. Simple monolithic collapse models predict well-defined MDFs, with total system mass being the prime parameter defining the chemical enrichment history of the system (e.g. Arimoto & Yoshii, A&A, 173, 23). On the other hand, low mass systems that experience independent chemical enrichment histories prior to merging to produce larger spheroidal systems will have MDFs that depart from the monolithic collapse predictions.

MDFs can be determined from stars evolving on the red giant branch (RGB). While spectroscopy is the prefered means for determining metallicities, this can only be applied to systems within a few Mpc given that stars near the RGB-tip have $M_I \sim -4$. In any event, the strongest absorption features, such as the MgH bands at visible wavelengths or the near-infrared Ca triplet, only monitor the abundances of certain elements, and do not track mean metallicity. The photometric properties of giants provide another means of determining metallicities in stellar systems with ages < 3 Gyr, where the effects of age on RGB colors are minor, and this technique can be applied out to distances in excess of 10 Mpc using AO-compensated data obtained with an 8 metre telescope.

The greatest sensitivity for photometric metallicity determinations occurs on the upper 1 mag of the RGB. A complicating factor is that this portion of the RGB contains the stars with the coolest effective temperatures, and if these have metallicities that are solar or higher then the spectral-energy distributions at visible wavelengths will be affected by line-blanketing, with the result that at wavelengths shortward of 1 micron these objects will be significantly fainter than more metal-poor giants with comparable ages. This introduces a bias against detecting the most metal-rich stars. The effects of line blanketing are much reduced at infrared wavelengths, and deep J and K images can be used to construct MDFs spanning the full range of metallicities.

HST has been used to investigate the MDF of galaxies as distant as Cen A (r ~ 3 Mpc, Harris et al. 1999, AJ, 117, 855). An intriguing result is that the MDF of this galaxy can not be modelled by a simple one-zone chemical enrichment model. Rather, the MDF appears to require at least two enrichment events, which Harris et al. (1999) suggest are the result of two collapse episodes. The MDF of the Local Group compact elliptical galaxy M32, as constructed by Grillmair et al. (1996, AJ, 112, 1975), is remarkably similar to that of Cen A, despite obvious differences in environment and integrated system mass. These data suggest that the star forming histories of spheroidal systems may be very different from that predicted by traditional models.

With MCAO on Gemini it will be possible to obtain deep J and K images sampling the RGB-tips of spheroidal systems and spiral galaxy disks out to distances that include the Virgo cluster; hence, MDFs could be constructed for systems spanning a range of masses, environment, and morphologies. These observations require diffraction-limited image quality to obtain reliable photometric measurements of stars that are, by traditional standards, extremely faint, and also to resolve individual objects in very crowded environments. Field of view is also of great importance as large numbers of stars must be surveyed to properly sample the entire range of metallicities in a system, and a moderately stable PSF across the field is essential.

2.2.1 Program Summary:

Intrinsic brightnesses of sources:

M_K = -6.5 (RGB-tip)

Observables:

Deep J and K images, with 10-sigma accuracy at K = 24 (RGB-tip in the Virgo cluster)

Sample targets:

Maffei 1, NGC 3379, Virgo cluster ellipticals and spirals

Observing Requirements:

- diffraction limited resolution (a Strehl ratio in excess of 0.3; this will require 10 percentile seeing in J)
- stable PSF over a field comparable to the scale lengths of bulges and ellipticals in the Virgo cluster (ie. 30 - 40 arcsec)

Key diagnostics: (K, J-K) CMD

2.3 Intergalactic Stars (Ted von Hippel)

The formation of galaxy clusters involved interactions and mergers of galaxies, the injection of hot gas into the intergalactic medium via galactic winds, and the tidal ablation of stars from the mean gravitational shear of the cluster. It is likely that most of this activity occurred during the initial collapse phase of the cluster (Merritt 1984, ApJ, 276, 26), leaving stars floating freely in the overall cluster potential. Numerical simulations suggest that between 10% and 70% of the initial mass in galaxies is released into the intergalactic medium (Miller 1983, ApJ, 268, 495). Recently Ferguson, Tanvir, & von Hippel (1998, Nature, 391, 461) employed deep HST I-band observations to directly detect intergalactic red giant branch stars in the Virgo cluster. They found that 5 to 10% of the stars in the Virgo cluster are in the intergalactic component within the observed cluster radius. Observations of intergalactic planetary nebulae in both Virgo (Feldmeier et al. 1998, ApJ, 503, 109) and Fornax (Theuns & Warren 1996, MNRAS, in press) arrive at even more substantial intergalactic populations. Observations of intergalactic red giants and planetary nebulae offer exciting possibilities to a) probe galaxy cluster mass distributions via planetary nebulae radial velocities, b) determine the source of the intergalactic stars by measuring their metallicities, and c) determine the interplay of galaxy collisions versus violent relaxation of the cluster via the distribution of intergalactic stars throughout the cluster.

It is unlikely that the diffuse stellar component in galaxy clusters will be distributed uniformly. Low luminosity dwarf galaxies, like those surrounding the Milky Way, will appear as loose concentrations of stars, while fragments of relatively recent collisions may persist as coherent streams of material. Finally, galaxies passing through the diffuse sea of stars will presumably leave a wake.

Nothing is known about the MDF of the diffuse stellar population, and there are no published predictions. It can be anticipated that the stars should be relatively metal poor when compared with the mean luminosity-weighted metallicity for the visible galaxies, as tidal effects will tend to strip the most loosely bound objects, which are located in the outskirts of galaxies, and hence are metal-poor. A direct measurement of the MDF of the intergalactic population is a first step to understanding its relationship to the visible galaxies.

A more obvious prediction is that the MDF of the intergalactic population should be spatially uniform. The visible galaxies in Virgo constitute a uniform population, in the sense that metal-rich and metal-poor galaxies have roughly the same degree of central concentration. Hence, there should not be a radial gradient in the metallicity of the intergalactic stellar population. If one were found, it would have profound implications for understanding cluster evolution, since it could imply that the intergalactic stars formed in situ from, for example, the cluster cooling flow. The search for radial abundance gradients is relatively straightforward, since it relies only on a differential comparison of fields, rather than an absolute calibration of the photometric system.

While the ability to measure planetary nebulae radial velocities is just within reach of ground-based 8 and 10 meter telescopes with existing or planned optical spectrographs, efforts to fully probe the gravitational potential of the intergalactic stars must await much larger telescopes and/or wide-field AO (i.e. MCAO). The initial detection of the intergalactic population in Virgo required just over nine hours with HST in the I-band, and measurements at shorter wavelengths will be difficult to obtain given the cool temperatures of these stars. However, these objects are detectable in JHK, and photometric measurements at these wavelengths are required to measure the color of these stars, and thereby their metallicity. We expect the detection of the tip of the RGB in the near-infrared to take a few hours with MCAO on Gemini. Dozens of fields are required to measure the spatial profile of the intergalactic population, as well as to test for metallicity differences as a function of cluster position; consequently, studies of the intergalactic population are well-suited to MCAO.

2.3.1 Program Summary

Intrinsic brightness of target sources:

M_K = -6.5 (RGB-tip)

Observables:

Deep J and K images, with 10-sigma accuracy at K = 24 (the RGB-tip in the Virgo cluster). Crowding is not a problem.

Sample targets:

Fields in Virgo cluster sampling a range of cluster positions. This same technique may also be applied to the Fornax cluster.

Observing Requirements:

- diffraction limited resolution (Strehl ratios in excess of 0.2 - 0.3 in K; superb imaging conditions will be required in J)
- a stable PSF over a field comparable to galaxy scale lengths in Virgo (i.e. on the order of arcminutes)
- control fields to measure the densities of foreground and background sources.

Key diagnostics: (K, J-K) CMD

2.4 Extragalactic Globular Clusters (Ray Sharples)

Globular clusters (GCs) are homogeneous stellar systems containing stars of a predominantly single age and metallicity. They are the brightest individual objects that can be resolved in early-type galaxies, and hence can be used to study the properties of these systems to larger distances than is possible with resolved stars. Although the relative efficiency of star formation in GCs with respect to the field is not fully understood, there is good evidence that GCs form during starburst activity, which might occur during the initial collapse of a protogalaxy, or during major merger events; hence, GCs provide an important probe of critical episodes in the star formation and chemical enrichment history of their host galaxy.

A key development has been the discovery that the GC systems in many elliptical galaxies have bimodal color distributions. This indicates the presence of at least two distinct GC populations, with different ages and/or metallicities. The systematic properties of how the subpopulations vary with properties such as galaxy luminosity and environment are still poorly understood.

The comparison of GC subpopulation properties with model predictions (e.g. Ashman & Zepf 1992; Forbes et al. 1997) can help constrain and improve galaxy formation theories. The key to testing the different models is in determining the age, metallicity and kinematics of the GC subpopulations over a range of environments.

Spectroscopy provides the most direct method for determining cluster properties. However, obtaining these data can be a time consuming process, which is only feasible on 8-10m class telescopes for the closest ellipticals. On the other hand, imaging studies can sample a much larger number of GCs, while providing information on the spatial distribution and broad-band colours of clusters. An added benefit of imaging is that for nearby galaxies direct measurements of cluster tidal radii (r_t=0.6 arcsec at D=10 Mpc) and ellipticities can be made, which would allow constraints to be placed on the orbit eccentricities due to tidal truncation. Finally, with imaging data it will be possible to study the GC luminosity function, which will provide insight into the dynamical evolution of the GC system.

Contamination from foreground stars and background galaxies is a complicating factor for imaging studies, although stars and galaxies can be identified using the size and spatial distribution of sources. Luminous old GCs have half-light radii in the range 3-5pc. With HST/WFPC2, clean samples of GC candidates have been isolated on the basis of image parameters out to D=15 Mpc (r_e=0.04-0.07 arcsec; Gebhardt & Kissler-Patig 1999). The spatial distribution of GCs closely follows that of the parent galaxies, with typically half of the cluster population contained within 1-2 arcmin of the centre, which is well matched to the corrected field of MCAO.

So far, the discussion has focused on populations of old GCs. However, populations of apparently young GCs have been identified in recent merger remnants (e.g. Holtzman et al 1992; Zepf et al 1999). The most luminous of these are significantly brighter than the most luminous clusters in the Milky Way. Deep MCAO images would enable the structural parameters of these objects to be probed to determine if they will eventually evolve into a population with characteristics similar to old GCs. If a direct link can be established then studies of young GC systems may provide clues into conditions that prevailed during the early stages of galaxy formation.

2.4.1 Program Summary

Intrinsic brightness of sources:

M_H = -14 (brightest GCs), M_H = -10 (GCs at turn-over point in the LF)

Observables:

Deep I and H images. To observe GC systems in the Coma cluster (μ_0 = 35), and hence sample a range of extreme environments, it will be necessary to obtain photometry with 10-sigma accuracy at H = 25. These observations would be supported with deep optical imaging from the ground and with the HST + ACS.

Sample targets:

Early type galaxies in Virgo, Fornax, and Coma clusters. Merger remnants with $\mu_0 = 34$ (N1275, N3256, N4038, N3597, N7252), and selected field galaxies.

Observing Requirements:

- diffraction-limited imaging in H, with S/N = 20 at H = 25 (and K?)
- stable PSF over 1 - 2 elliptical galaxy scalelengths in the Virgo cluster (i.e. 40 - 80 arcsec)
- natural tip-tilt star constellation must be able to cope with large extended objects (half-light radii ~1') in the field!

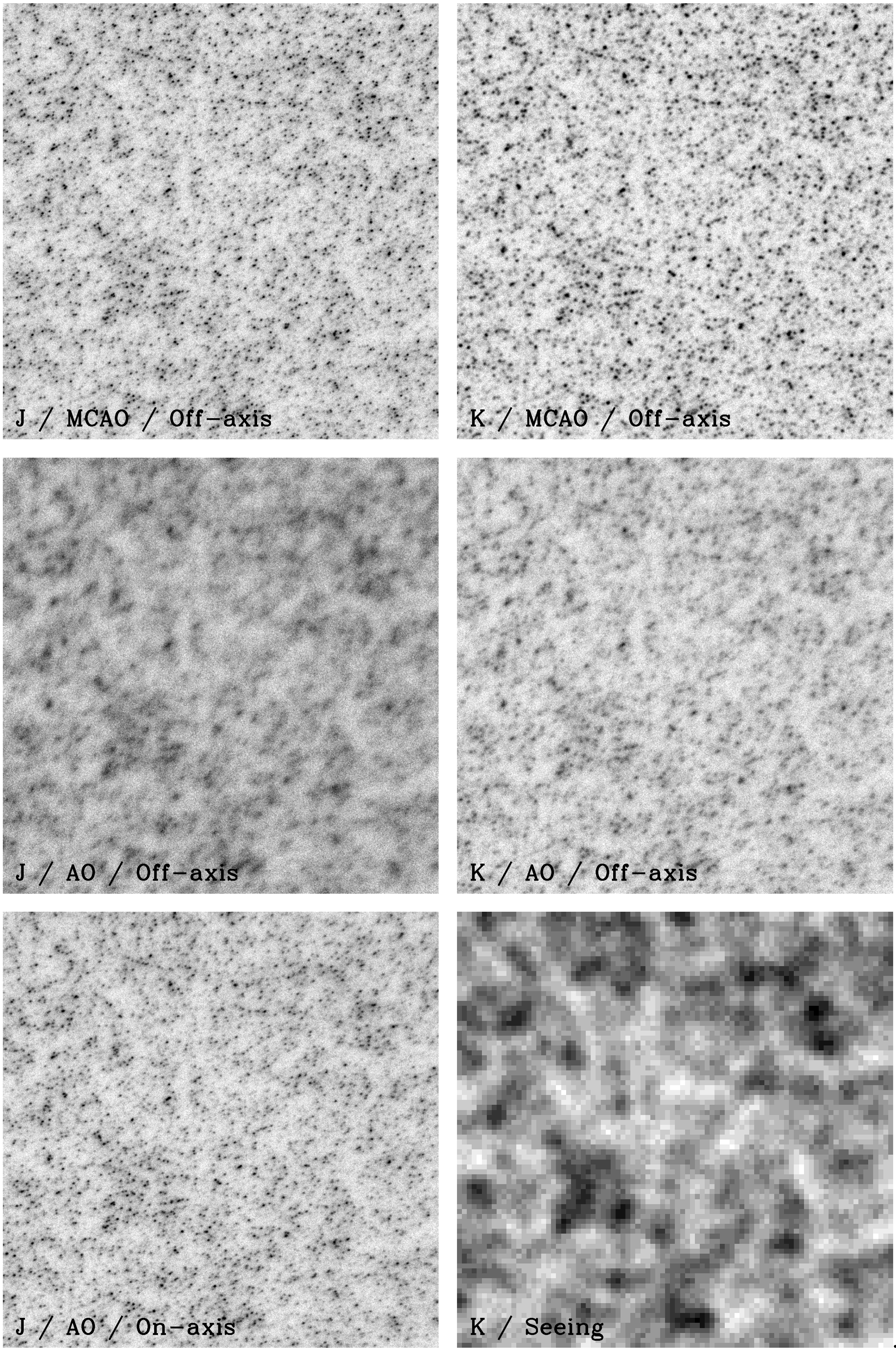
Key diagnostics:

- (I-H) [and (J-K)?] colours
- H [and K?] LF
- Image concentration index to probe the structure of individual GCs in nearby (ie. r < 10 Mpc) systems

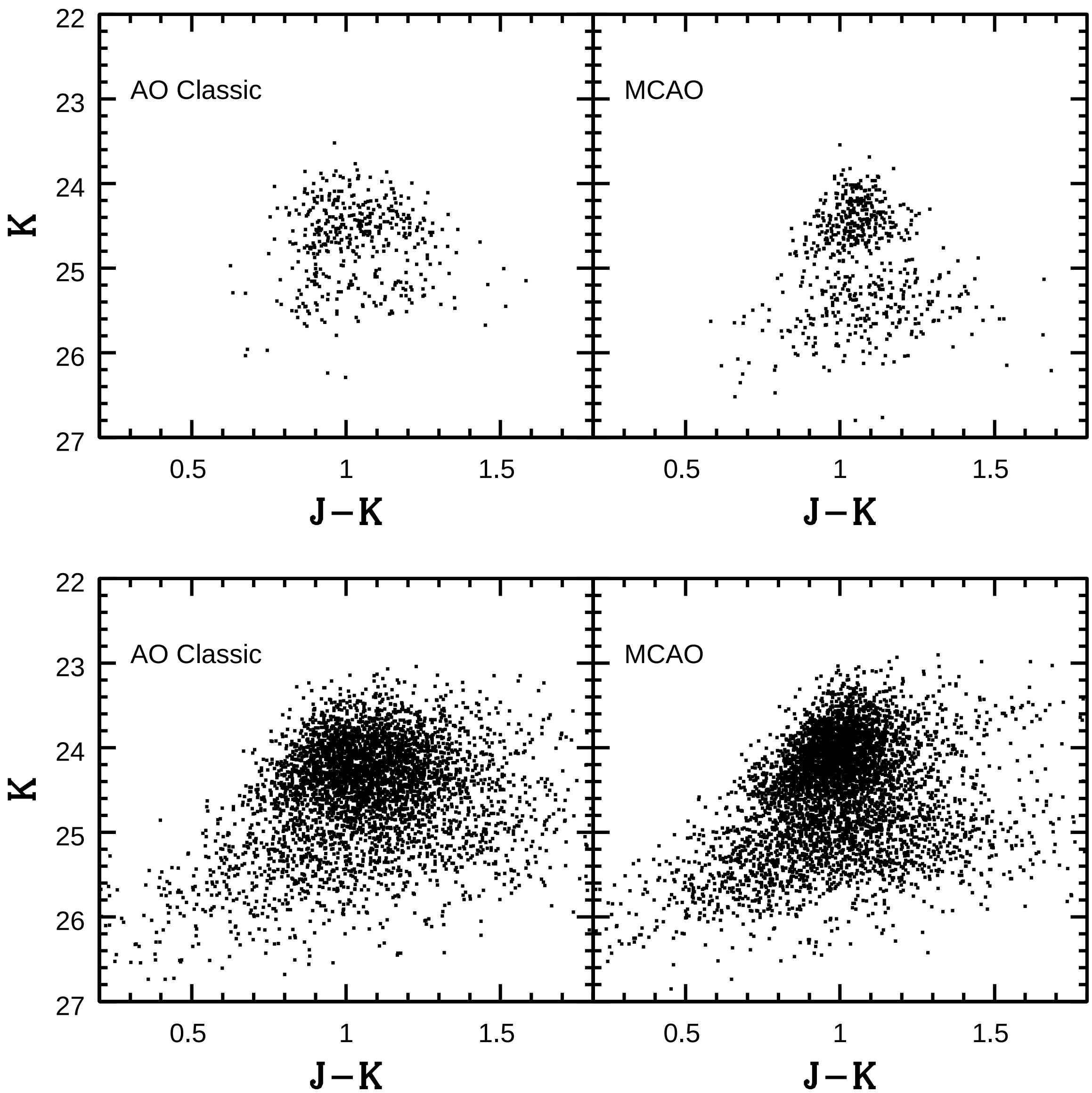
3 SIMULATIONS

Models of crowded stellar fields have been used to assess the benefits of MCAO with respect to conventional single-star AO. Model images corresponding to those produced by a conventional single star AO system and an MCAO were were constructed by Francois Rigaut. The models include the effects of anisoplanicity appropriate for conventional AO and MCAO. Two crowding regimes were considered: a moderately crowded field containing 1000 sources between K = 24 and K = 25 distributed over a 1 square arcmin field, and a severely crowded field containing 10000 stars in the same brightness interval. This brightness range was selected because it corresponds to the top magnitude of the giant branch at the distance of Virgo. A population of fainter stars extending to K = 26.5, in numbers that followed a power-law LF with exponent 0.3, which holds throughout the upper portions of the Galactic bulge (Davidge 2000, submitted to AJ), was also added to form a background. Stars between K = 23.5 and 24 were also added, in numbers that correspond to 25% of those between K = 24 and 24.5, to represent an AGB component. All stars have J-K = 1, which is a roughly appropriate for a metal-rich population. Noise was included that corresponded to an integration time of 6 hours on Gemini.

The brightnesses of individual stars were then measured using the PSF-fitting routine ALLSTAR. The PSF is a critical element of this analysis. For conventional AO it is clearly desirable to construct a PSF that is variable across the field, to correct the effects of anisoplanicity. However, it is very difficult to construct a variable PSF in crowded fields using current photometry routines, since the effects of crowding and PSF variability can not be de-coupled unless a large number of very bright objects are present. Given this difficulty, a single PSF was constructed for each filter + field combination.


J / MCAO / Off-axis
K / MCAO / Off-axis
J / AO / Off-axis
K / AO / Off-axis
J / AO / On-axis
K / Seeing

Caption of Figure 1 (previous page): Images generated for the analysis. Each image is 11"x11" (full images are 15.9"x15.9"). "On-axis" refers to images centered on the AO guide star or in the MCAO field. "Off-axis" images shown here are centered on a point 30" away from the AO guide star / MCAO field center, in a corner of the 1'x1' MCAO field. Not shown is the seeing limited J band image (very similar to the K seeing image) and the On-axis K band image, which is very similar to the off-axis MCAO K band image. The On-axis J and K band MCAO images are basically identical to their off-axis counterpart, and are not shown.



Observations of globular clusters with the CFHT AOB indicates that a single PSF introduces photometric errors of only a few hundredths of a mag (Davidge & Courteau 1999, AJ, 117, 1297; Davidge 2000, ApJS, 126, 105) in (K, J-K) CMDs over a 30 arcsec field of view during median seeing conditions. Given the inability to track PSF variations, the analysis was restricted to a 20 x 20 arcsec field in an effort to present a comparison that is most favorable for conventional AO; comparisons over a larger field will be explored at a later date.

The CMDs constructed from both crowding cases are compared in the figure; the results for the moderately crowded case are shown in the top row, while those for the severe crowding case are shown in the lower row. Significant differences between the conventional AO and MCAO CMDs are clearly evident, in that the CMDs constructed from the MCAO data have less scatter and extend to deeper brightnesses. Hence, even in a 20 x 20 arcsec field of view, where the effects of PSF variations are modest, MCAO has a distinct advantage with respect to conventional AO for photometric programs that utilize the current generation of photometric tools (ie. that are best suited for constructing a single PSF). If extended to data covering an even larger field of view the differences between results generated with MCAO and conventional AO will become even larger.

4 BASIC REQUIREMENTS

The following basic requirements can be drawn from the science cases described above:

1. The MCAO system must be capable of delivering a moderately high Strehl ratio. It is the experience of one of us (TD) that significant improvements in photometric performance occur when the Strehl ratio exceeds a few tenths.
2. The MCAO system must be capable of exploiting the best imaging conditions. This is of particular importance for the J band, as even modest Strehl ratios near 1.3 microns require superb imaging conditions. This means that the MCAO system must be deployable on a short time scale so that rare seeing opportunities can be exploited.
3. The integration times for the programs described above are lengthy (on the order of a night), and so the MCAO system must be capable of working for long periods of time. This means that the system should be insensitive to changes in sky background (which will vary with the phase of the moon, and may effect the ability to use faint guide stars), and sky transparency (e.g. if clouds are present).

Finally, studies of globular clusters with the CFHT AOB indicate that the typical atmospheric conditions on Mauna Kea are such that good photometric performance (i.e. errors in photometric brightness of a few percent) can be achieved over the 30 x 30 arcsec field of the KIR imager (e.g. Davidge & Courteau 1999, AJ, 117, 1297, Davidge 2000, ApJS, 126, 105). To be worthwhile, the Gemini MCAO must be capable of significantly improving upon this observing efficiency. This is not simply a matter of enhancing the field of view, since if the Strehl ratio is degraded markedly then there will be a loss in efficiency.