GMOS Operational Concepts Definition Document (2.0)

Appendix: Detailed Observing Scenarios

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This appendix includes detailed observing scenarios which elaborate on the generic observing scenarios presented in the main document. These deal with integral field spectroscopy of brightest cluster galaxies at z=0.2, multiaperture spectroscopy of dwarf spheroidal galaxies to determine their mass-to-light ratio and multiaperture spectroscopy of very faint galaxies using GMOS with adaptive optics. We are grateful to colleagues who have helped us with their preparation.

1. Dark matter in dwarf spheroidal galaxies

1.1 Introduction

It is important to determine the mass-to-light ratio in different stellar systems in order to establish the smallest scale on which large quantities of dark matter exist. This may yield clues about the nature of the dark matter since relativistic particles (e.g. neutrinos) cannot cluster on very small scales. For this reason, various workers have measured the dynamics within globular clusters and dwarf spheroidal (dSph) galaxies. These are technically demanding observations since the velocity dispersions are only a few km/s. GMOS will allow this work to go much deeper due to the larger telescope aperture and the use of multiobject techniques. This means that more distant galaxies could be surveyed - out to the edge of the local group rather than just the nearest dSph galaxies, and that more stars in a given galaxy can be measured which will reduce the current large uncertainty in the dark matter content.

This scenario takes as its starting point the recent study of the dynamics of the Ursa Minor (UMi) dSph galaxy of Hargreaves *et al.* (MNRAS, 271, 693, 1994). They measured the velocities of 46 giant branch stars within a field of 32×23 arcmin^2 via the deep Calcium triplet lines around 850nm. They found a velocity dispersion of 7.5±1 km/s and evidence for solid body rotation. Their determination of the mass-to-light ratio was 59 (+41,-25) in solar units which implies the presence of a large amount of dark matter.

Although based on a particular example, this discussion should also be relevant to studies of globular clusters which require similar accuracy of individual velocity determination (~ 1km/s).

Much of the observing procedure has already been laid out in the generic multiaperture spectroscopy scenario in the main document so will not be repeated here. Most of this scenario is devoted to a discussion of the required observing configurations which are exceptionally demanding and will place strong limits on the functional requirements.

1.2 Dispersion options, stability and wavefront sensing

Taking the specific example of the UMi dSph galaxy, the required accuracy of each velocity measurement is ~ 1km/s. We must first find out the dispersion configuration and instrument stability which is required to achieve this accuracy.

The observations of Hargreaves *et al.* used the WHT ISIS spectrograph with a grating of ruling density ρ= 1200 /mm which gave a dispersion of 0.035nm and a resolving power of R = 12,140 at the observation wavelength of λ= 850 nm. The slit width was 1 arcsec which is well matched to typical seeing at La Palma.

It is quite difficult to provide the same resolving power with GMOS because the pupil diameter is smaller than ISIS (100mm cf 150mm) and because the resolving power is inversely proportional to the telescope aperture. This means that a similar grating setup would yield a resolving power of only R ~ 4,300. However, GMOS does have the advantage that a narrower slit can be used, especially since the targets are stars. A simple scaling from the ISIS observations implies a slit width of only 0.36 arcsec which means that the observations should take place in good seeing.

The table gives some examples of GMOS dispersion configurations that will give R=12,000

Dispersion configuration options

ρ (/mm)	α (deg)	ϕ (deg)	Dila-tion	Δλ (nm)	Slit (")	Over-sample	T_G	T_S	Δv_L (km/s)	Field (')
1800	22.2	32	1.39	64	0.50	4.5	1.00	0.89	1.1	1.7
1200	1.0	34	0.98	87	0.27	3.9	1.00	0.50	1.3	2.7
1200	56.0	0	1.76	104	0.39	2.8	0.57	0.61	1.8	3.1
900	47.0	0	1.46	122	0.24	2.0	0.96	0.48	2.5	3.7

Here ρ is the ruling density, α is the tilt of the front surface of the grating unit, ϕ is the vertex angle of the immersion prism (ϕ= 0 if unimmersed), *Dilation* is the beam dilation factor at the camera, Δλ is the wavelength range that fits on the detector, *Slit* is the slit width required, *Oversample* is the number of detector pixels in the resolution element, T_G is the relative throughput of the optical system (excluding slit throughput) assuming that camera is designed to accept a beam dilated by a factor of 1.4, T_S is the slit throughput in *best seeing* as discussed below, Δv_L is the limiting velocity accuracy discussed below, and *Field* is the available field left over for positioning the targets away from the centre line of the field of view so that the wavelength range 830-875nm is always on the detector. The first two examples are for *immersed* gratings which are the ideal choice because they permit the use of a relatively wide slit which improves the throughput and is less sensitive to seeing conditions. The other examples are for unimmersed gratings. The third example implies produce low throughput because it requires a narrow slit and overfills the camera. The fourth option requires the narrowest slit of all and a consequent loss of throughput in all except the most exceptional seeing.

The velocity accuracy as a function of magnitude depends not only on the resolving power but also on the slit width and errors in locating the centroid of each line. The centroid errors arise because of tracking errors which move the star image with respect to the slit and because of flexure in the instrument which moves the image of the slit with respect to the detector. It has been assumed that the flexure in the instrument is 3μ m/hour at the detector, which corresponds to 0.016 arcsec on the sky.

The tracking accuracy is determined by the guide signal from the wavefront sensors (WFS) and any internal errors in the telescope control system. Neglecting the latter, the dominant error source should be the the flexure of the WFS probe with respect to the slit mask. To minimise this it is assumed that the images are guided and stabilised using the on-board wavefront sensor (OIWFS) rather than the peripheral wavefront sensors (PWFS). Assuming that the OIWFS flexure at the telescope focal surface is also 3μ m/hour, the total centroid error is 0.017 arcsec/hour assuming that the two sources of error can be combined in quadrature.

The limit this places on the velocity accuracy (for infinite signal/noise), if the wavelength calibration is repeated every hour, is listed in the table as Δv_L. Note that the wavelength calibration cannot account for tracking errors since the calibration unit cannot mimic the movement of the image on the slit. It may be possible to do better than this if the flexure varies smoothly with time.

To take into account photon noise due to the sky background, object continuum and CCD readout, we need to estimate the total throughput of the system. Ignoring slit losses, this is typically 0.25 for current grism-based multiaperture spectrographs (e.g. LDSS-2) for which T_G=1.0. On this assumption the slit throughput can be estimated and is shown as T_S in the dispersion configuration table.

Figure 1 shows the estimated velocity accuracy as a function of magnitude for a single line in a 1 hour observation assuming a total throughput of 0.25 T_G T_S and a sky brightness in I of 19.4 mag/arcsec^2, appropriate for a dark night. Figure 2 shows an equivalent plot for average seeing assuming that the effective PSF is twice as broad as for best seeing. As expected the limiting magnitude for a given velocity accuracy is brighter in the worse seeing.

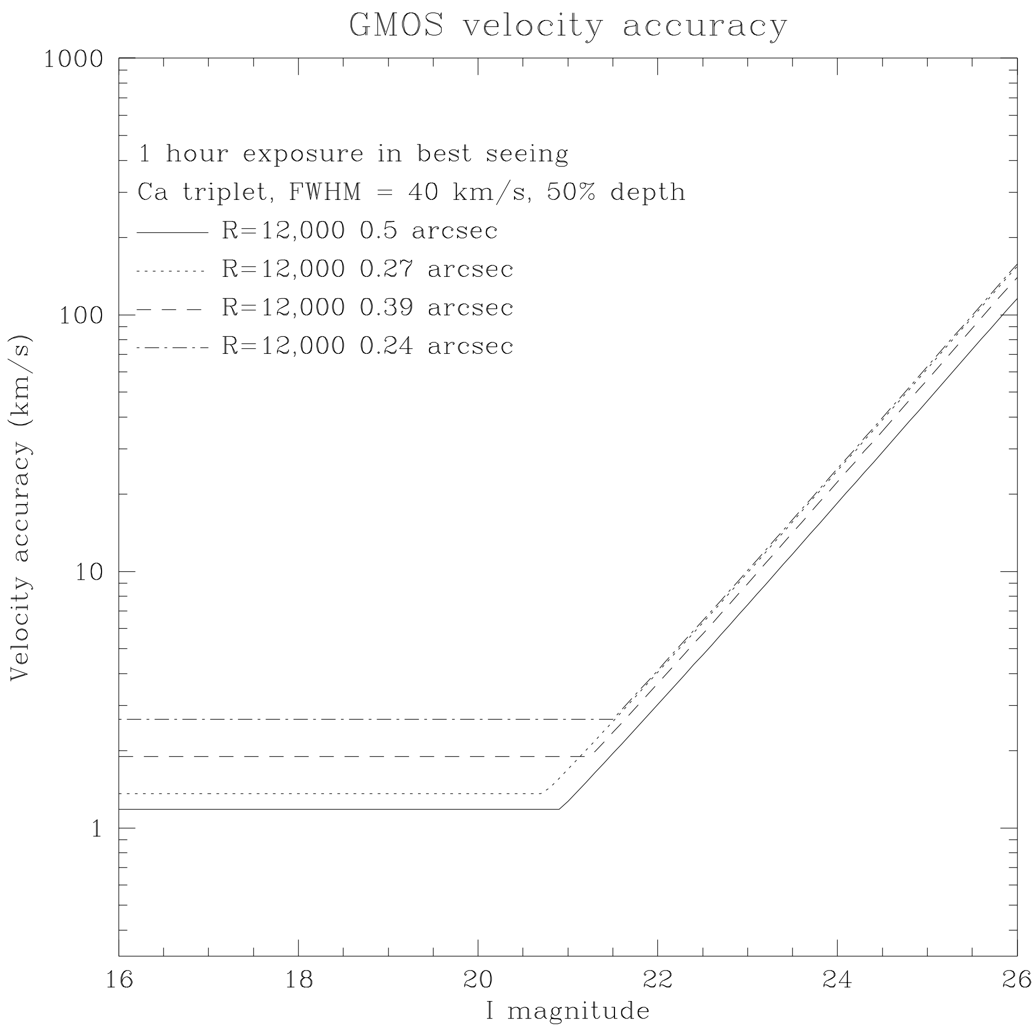

Figure 1*: The variation of velocity accuracy with magnitude for a single line typical of those that make up the Calcium triplet in giant K-stars. The four traces are for the dispersion configurations given in the text, which all give R=12,000. The image profile is that predicted for the median guide star brightness in a patrol field between 5.5 and 7 arcmin diameter assuming best seeing (0.25 arcsec FWHM). The velocity accuracy is limited at bright magnitudes by the combination of instrument flexure and telescope tracking.*

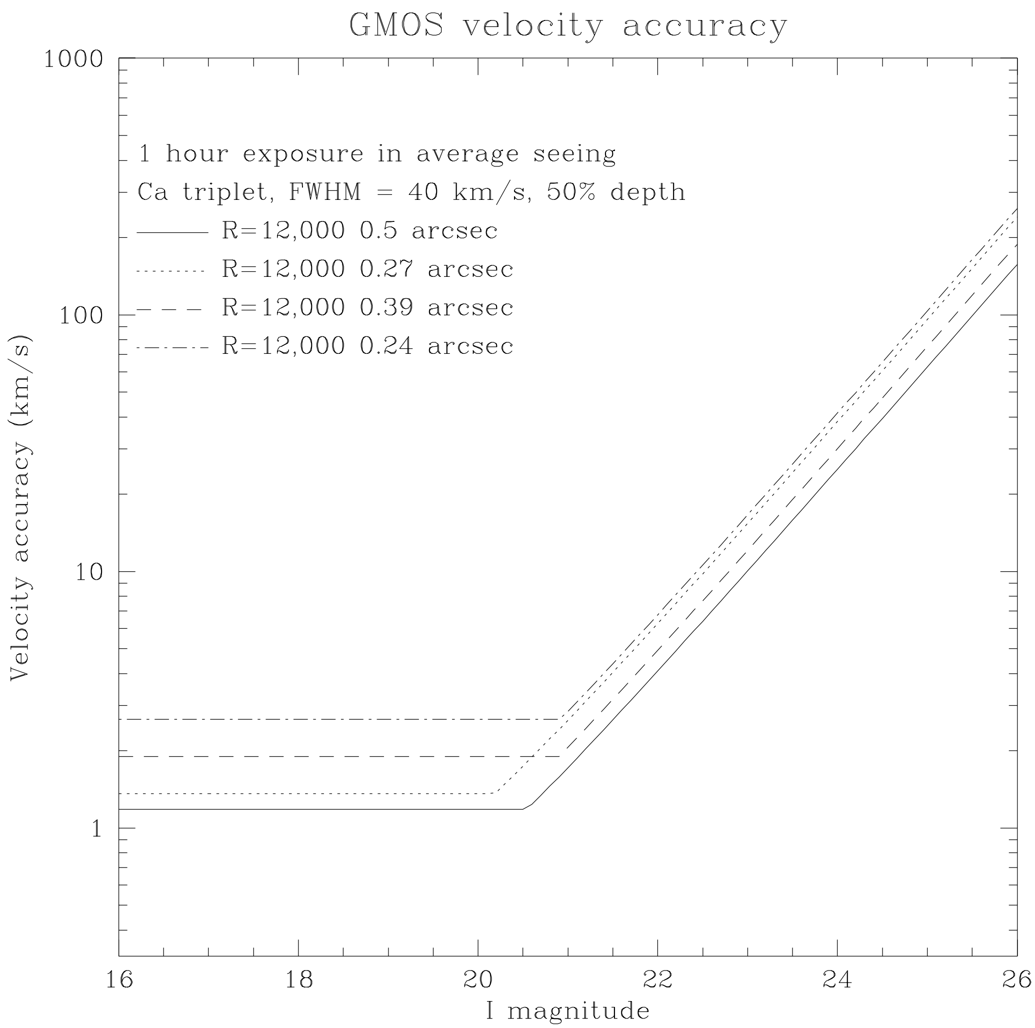

Figure 2: *The same as Figure 1 but for average seeing*

1.3 Depth of the observations

For these observations we require a velocity accuracy of < 2km/s. The chosen stars in the UMi galaxy stars have 14.4 < I < 17.4. It can be seen that the unimmersed grating with ρ=900 /mm would require multiple exposures of shorter duration than 1 hour since Δv_L >2 km/s. However the other configurations would achieve the required accuracy with hourly calibration only. The magnitude limit for this type of observation in 1 hour appears to be I ~21 which means that it would be possible to carry out this type of observation with hour-long exposures for a similar galaxy out to a distance of 420kpc when using the ρ=1800 /mm option.

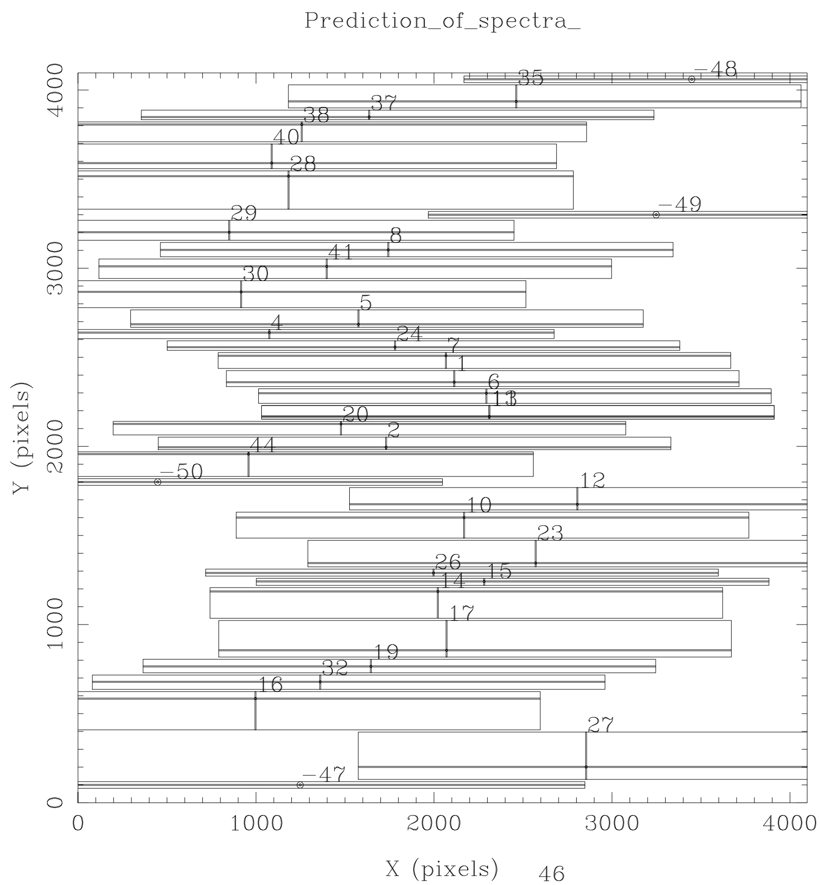

Figure3 :*An example mask layout projected onto the detector area for a galaxy 5.8 times more distant than the UMi dSph galaxy based on the stars observed by Hargreaves et al.. Dispersion increases from left to right and the boxes indicate the full extent of the spectra (830-875nm). Within each box the slit is shown by a centrally-placed vertical line and the object spectrum by a horizontal line. The minimum slit length is 10 arcsec. The mask was designed using the LEXT package written for LDSS-2. 30 of the 46 programme stars are addressed by this mask. The four holes for field acquisition are labelled with negative numbers.*

Hargreaves *et al.* observed each star individually because the field covered by the galaxy was large (32×23 arcmin^2) and ISIS has no multiobject capability. Even with GMOS's multiobject capability, only 2.5 stars would appear on average in each field. However, if the UMi galaxy was placed 5.8 times further away, it would fit entirely within the GMOS field of view of 5.5×5.5 arcmin^2. This would permit the entire galaxy to be observed with only a few exposures of 1 hour each, depending on the way in which the target stars were selected. If they could be chosen to optimise the mask design, i.e. with roughly equal spacing (5-6 arcsec) in the cross-dispersion direction, one mask might be sufficient (except for the first dispersion configuration in the table, which does not give an adequate field in the dispersion direction). An example is shown in Figure 3 which gives a possible mask design which addresses 30 of the 46 target stars used by Hargreaves *et al.* on the assumption that the entire galaxy is at a distance of 370kpc so that the surveyed field fits within the GMOS field. This also shows the location of a number of holes through which a number of brighter stars can be observed for acquisition.

By taking multiple exposures, it would be possible to go much fainter to measure the dynamics of such galaxies to even greater depths. In 8 hours, 2km/s should be possible to I=22.6 with the immersed ρ=1800 /mm option which implies a depth of 740kpc. This would allow any dSph galaxy in the local group to be surveyed in the equivalent of a single night. Alternatively, less luminous stars could be studied in nearer galaxies to improve the statistics or to investigate higher moments of the velocity distribution and to investigate possible bias due to the sampling of the stellar population. Note that the best stars for this work are those closest to the main sequence turnoff rather then the very bright stars studied at present.

1.4 Field distortion

We have seen how the instrument could be configured to carry out these observations to unprecedented depths. However there is an important limitation imposed by atmospheric distortion.

Firstly, we consider the chromatic effect (atmospheric dispersion). It is assumed that the atmospheric dispersion corrector (ADC) will remove the distortion in the *shapes* of the images to an acceptable level that is small compared with the predicted image size (50% EED = 0.3 arcsec in best seeing) so as to maximise the slit throughput. Note that the wavelength range of the observations is only 45nm.

The ADC will correct for atmospheric distortion (for zenith distances less than 60 deg), but introduce distortions in the field as it tracks across the sky. This will make the images of the objects in the field move with respect to each other resulting in velocity errors. Moreover, the distortions may increase with radius within the field, to give the illusion of a radial velocity gradient. The atmosphere also produces a (non-chromatic) cylindrical distortion oriented at the parallactic angle. This has a similar qualitative effect to the ADC distortions.

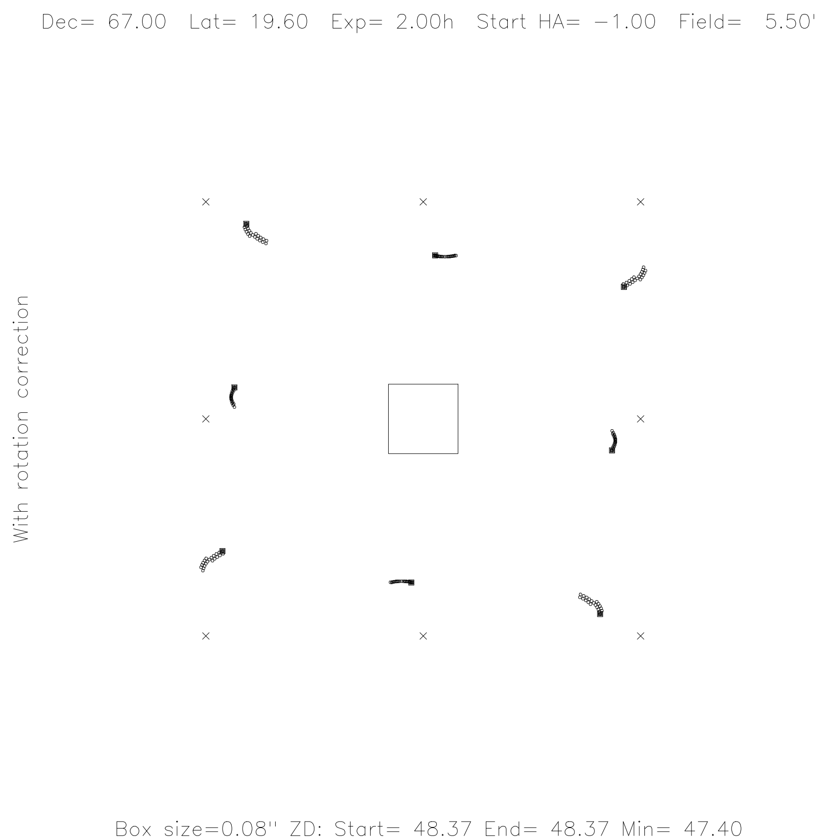

Figure 4: The effect of atmospheric distortion for observations of the Ursa Minor dSph galaxy over two hours around transit. The apparent motions of eight points on the periphery of the 5.5×5.5 arcmin² field of view are plotted, referenced to the centre of the field. In this simulation the apparent rotation of the field has been removed, referenced to the start of the observation. The scale is indicated by the box which has a side of 0.08 arcsec. The crosses mark the undistorted positions.

To estimate the size of the *atmospheric distortion* (only) at Mauna Kea, the motion of points at the corners of the 5.5× 5.5 arcmin field were estimated for a track of 2 hours at transit with the average rotation of the field removed. The result is shown in Figure 4. The results of these simulations suggest that the allowable range of hour angle for a single mask is about ± 1 hours for the full field and ± 2 hours if only the central 3 arcmin of the field was used. Therefore a mask covering the full field of view could only be used over a window of two hours around transit. Objects which transit at greater zenith distance will suffer even greater restrictions.

The effect of the ADC has not been modelled in such a deterministic way, but the overall level of distortion has been estimated by ray-tracing the `B' design produced by Chris Morbey (Oct 1996) and its effect analysed in *The effect of ADC and atmospheric distortion: Jeremy Allington-Smith, 21 Oct 1996*. From this it can be seen that for an observation of the UMi dSph at declination 67 deg, whose minimum zenith distance is ZD(min) = 53 deg, the expected distortion from the ADC alone is 57 mas (0.71 pixels), compared with about 33 mas from the atmosphere alone. This would result in a maximum velocity error of 6.8 km/s for a slit width of 0.25 arcsec. In other words, the velocities of object at the edge of the field would be wrong by up to this amount. This is clearly unacceptable so the ADC should be turned off, i.e. set at the configuration appropriate for the minimum zenith distance. This will result in some chromatic errors in flux calibration and a possible reduction in signal/noise but will not affect the relative velocities of the stars measured in each exposure. There is also the option of keeping the ADC on (i.e. continously tracking) and designing the mask to take into account the combination of ther atmosphere and ADC distortions (at the minimum zenith distance) but, since the combined distortion is nearly three times greater than for the atmosphere alone, the time/elevation window within which such a mask could be used will be unrealistically short. Another option is to restrict the field size, but this would have to shrink to less than 1 arcmin before the ADC distortion was reduced to acceptable levels.

1.5 Observing procedure

The general procedure to be followed is laid out in the generic multiaperture spectroscopy scenario. Only deviations or additions will be mentioned here.

- **Mask design**. The masks will need to be designed after the targets have been carefully selected by inspection of direct images in various passbands to yield un-confused giant branch stars which are most likely to have a strong Calcium triplet (K-stars). For the more distant or concentrated stellar systems, this will require good seeing - at least as good as that required for the spectroscopy. If possible, the stars should be chosen so as to minimise the number of masks required. The direct images should be taken with GMOS some time ahead of the spectroscopy to give plenty of time for careful pre-planning. The relative positions of the stars should be determined to great accuracy, < 0.01 arcsec, so that the astrometry contributes negligibly to the star-to-star velocity accuracy. The images taken with GMOS should be long enough to allow the relative centroids to be determined to about one-tenth of a pixel. If it is also necessary to measure the systemic velocity to great precision, the positions of the target stars relative to the acquisition stars should also be of appropriate accuracy. The choice of slit width and the range of altitude over which a particular mask can be used was discussed above.

- **Target acquisition**. The method suggested in the generic multiaperture spectroscopy scenario, whereby the acquisition stars are imaged through holes in the mask, is strongly preferred since it is immune to mask repositioning errors which might occur if the mask was removed and reinserted into the light path to take a direct image of the sky. The absolute acquisition accuracy is not of great importance in measuring the velocity dispersion alone but is important if absolute velocity calibration is required relative to a radial velocity standard. It should be possible to measure the centroid of the acquisition stars very precisely with respect to the geometric centres of the holes so that the required telescope offset (including rotation) can be precisely determined and applied (in closed loop). On average we expect to find at least 5 stars of R=18.8 in the field (scaling from calculations by the A&G group) at this galactic latitude. Each will be detected with a signal/noise of ~ 200 in a 10s exposure which would allow the centroids of the images (0.3 arcsec 50% EED) to be calculated to ~ 1.5 milliarcsec. Although it would be wise to check the tracking by taking periodic exposures of the acquisition stars through the mask to make sure that the position registration was secure, this would have the drawback of requiring the grating to be removed from the light path which would expose the observations to grating repositioning error.

- **Guiding strategy**. The choice of patrol field and wavefront sensor was discussed above. The reference stars for both the PWFS (for tracking when the OIWFS is occulted by the calibration system) and OIWFS must be carefully chosen during the pre-planning stage. They must not occult the slits and must be bright enough so give the required image quality so as to maximise slit throughput and reduce tracking errors. From the discussion above, the star should have $R <$ 18.8 and we expect ~ 3 such stars within the an annular guide field between 5.5 and 7 arcmin diameter. In addition, a reference star is required for the active optics system. This would normally be well outside the GMOS science field.

- **Atmospheric dispersion compensation**. This is not essential *provided* that the guiding is done at the same wavelength as the observation (850nm) since the wavelength range is small and relative spectrophotometry is not required. If the ADC was not used this would require that the OIWFS was equipped with a large battery of passband filters. However we anticipate that the ADC will always be available so this problem does not arise. It is *essential* that the ADC does not introduce any field-dependent position errors while tracking (above ~ 0.01 arcsec/hour).

- **Time of observation**. As discussed above the high positional accuracy required means that the each mask for the UMi field can only be used within a time window of ~ 2 hours (longer for a smaller field) around transit. In many cases the observations will be restricted to times when the seeing conditions are very good in order to give the desired velocity accuracy. If necessary, several masks could be prepared for the same field configuration, but optimised for different observing conditions (seeing and/or hour angle).

- **Calibration**. Of great importance for these observations is *wavelength calibration*. This should be repeated as often as necessary to reduce instrument flexure errors to the desired level. In general, arc exposures should be interleaved with the on-target exposures which should be kept relatively short to minimise flexure problems. Flat fielding and bias exposures will be important to ensure that the data frames are clean enough to give good results when the spectra are cross-correlated to yield the relative velocity shifts between stars.

For the measurement of velocity dispersion alone, *radial velocity calibration* is not required since the reliability of the relative velocities is ensured by the use of small number of masks which may be cross-calibrated. However if the systemic velocity is also to be measured, it would be necessary to observe a radial velocity standard. It is important that the positions of both the standard and the programme stars are securely tied to those of the acquisition stars used for both the programme and calibration observations so that no systematic velocity error is introduced. Great care will need to be taken to ensure that the programme stars and the standards are acquired in exactly the same way to avoid systematic centroid errors. In general the calibration could be done with a generic single-slit mask.

Flux calibration is largely irrelevant here since only the wavelengths of the lines of the Calcium triplet have to be measured.

2. Brightest cluster galaxies at z=0.2

Brightest Cluster Galaxies (BCG's) are important cosmological probes since (1) they are standard candles, and can be used to study the nature of the Hubble flow over very large scales, and (2) there is a tendency for the axes of BCG's to be aligned with their host cluster, and perhaps even with other nearby clusters, so that BCG's may provide clues about the relationship between small and large scale structure. Given the importance of BCG's for cosmological studies, it is critical to develop an understanding of their evolution, and there is considerable debate about how and when BCG's formed. At one extreme it has been suggested that BCG's formed slowly due to the merging of cluster members. However, it has also been argued that BCG's were among the first galaxies to form, and that merging plays only a minor role in their evolution. If the former mechanism is correct then signatures of merger activity, such as distortions in the galaxy velocity field and areas of recent large-scale star formation, should be evident at intermediate redshifts.

This section describes the steps required to study the two-dimensional spectrum of BCG's at intermediate redshift using the Integral Field unit (IFU) on the Gemini Multi-Object Spectrograph (GMOS). The scientific goals of the observing program are: (1) to map the velocity field of stars and gas in BCGs and determine, for example, how the velocity dispersion and rotational velocity varies across the face of the galaxy; and (2) to study the spatial distribution of gas and stellar populations, using the strengths of various emission and absorption features (e.g. [OII]3727, Mg_2, etc). It is also necessary to obtain broad-band photometry *with the same observing configuration as the spectra* to measure surface brightnesses, as these data could be combined with the dynamical analysis to determine M/L ratios, which in turn are very important for probing the early chemical evolution of the target galaxies.

2.1 Feasibility and Observing Preparation

To meet the science goals, it is necessary to sample a portion of the galaxy spectra which contain (1) numerous narrow absorption features to provide velocity information; (2) deep, well-calibrated absorption features for studying stellar content; and (3) strong emission lines of Hydrogen and metals. These criteria are met in the rest frame wavelength interval 370-530nm, which corresponds to 440-640nm in the observed frame. A spectral resolution R = 2000 (ie. 150 km/sec) is required.

Data obtained as part of the Canadian Network for Observational Cosmology (CNOC) survey of intermediate redshift galaxy clusters indicates that the central surface brightnesses of BCG's at redshift 0.2 during median seeing conditions at CFHT are μ_V ~20 mag/square arcsec, extending down to ~23 mag/square arcsec 5 arcsec from the BCG centre (e.g. Davidge & Grinder 1995, AJ, in press). If the system throughput is half that of the CFHT MOS/SIS when used in imaging mode (the factor of one half is intended to account for the throughput of GMOS compared with MOS/SIS due to losses in the IFU, the use of a grating instead of grism, etc.), then the S/N ratio per lenslet per pixel (assuming that each spectral resolution element is distributed over two pixels) after a three hour integration is 10:1 at the center, and 2:1 in the outer regions if the sky level in *V* is 22.5 magnitudes per square arcsec. Clearly, it will be difficult to measure the strengths of absorption features in the outermost regions without binning the signal from adjacent lenslets; however, strong emission lines might still be detectable in individual elements.

Sky subtraction will be a critical consideration when extracting signal from low surface brightness objects. With ~1000 lenslets subtending 0.2 arcsec radii, the IFU module will have a field of view ~ 8 arcsec across. This is similar to that of most BCG's at z=0.2, which are typically extend over 5 - 10 arcsec, so it will be necessary to obtain the sky background spectrum from a region well away from the galaxy (and from other cluster members) to measure the background level. A number of options are available for background measurement. Perhaps the most obvious is to offset the telescope periodically to a pre-selected sky position. However, this greatly lowers observing efficiency, and produces sky measurements that are not simultaneous with the data - given that the sky level changes with time, the latter point is an important consideration for background limited cases. Another option would be to have fore-optics installed that would allow the field to be studied with two different spatial scales - a coarse scale would be available for sky measurements, while a fine scale would be used for the actual science observations. However, this approach is also not without its problems. Once again, it provides an inefficient use of telescope time, as two sets of observations must be recorded of each field. Moreover, to measure the background at distances 1 arcminute or more from the main science target, each lenslet would subtend ~1 arcsec on the sky and in some environments, such as crowded star fields, this lack of spatial resolution will hinder efforts to find representative background regions.

The most ideal means for measuring the background is to use subapertures positioned at various distances from the IFU. Such a setup would provide simultaneous sky measurements at moderately large distances from the science object. While it would be desirable to have the capability to position these subapertures, cost and space considerations make this highly unlikely. In the following, we assume that the sky background will be measured from subapertures at fixed locations in the science field.

Given that the central regions of clusters are crowded environments, and there is evidence for a diffuse light component in some clusters, the observer will need near science-quality processed images of the target cluster that indicate the extent of the BCG, and can be used to identify sky positions. In the following, we assume that these are obtained with the GMOS used in imaging mode. Finally, well in advance of observing the observer will have to evaluate the trade-offs between spatial and spectral coverage. Given that the main science goal of the program considered here is to map the spatial characteristics of BCG's, spatial coverage is probably of paramount importance, and the observer will have to order band-limiting filters to restrict the wavelength coverage of the observations. Two sets of filters will have to be used - one to observe the program galaxies, and the other for nearby radial velocity standards, which are NOT redshifted and will serve as templates for cross-correlation or Fourier Quotient analyses.

2.2 Observing Procedures

This scenario does not make a particular assumption about the operational scenario employed so the procedures apply to both queue-scheduled and classical observing. The tasks are divided between the telescope operator (*TO*) and the observer (*O*).

1. Check Observing Conditions
To obtain useable data, it is important that certain meteorological criteria be met. First and foremost, because of the low signal levels, the data should only be recorded on nights when the transparency is good. As for image quality, the program is best done during median to good seeing conditions (ie. FWHM ~0.5 arcsec or better). If either one of these conditions is not met, then a secondary program should be pursued.

2. Observe Flux Standard
If the observations discussed here are the first of the night to use the IFU, or if the unit has been dismounted and re-installed, then it will be necessary to check the instrument setup. This can be done by observing a moderately bright flux standard - a task that will need to be done anyway to

calibrate the galaxy observations. The observing procedure for a flux standard would be as follows:

a) Slew telescope to star location (TO)

b) While the telescope is slewing, use a guide star catalogue to identify a star that will be used to provide the reference signal for the primary mirror figure (aO) via one of the PWFS. This star could also be used to provide guiding information, as the exposure times are relatively short. (TO)

c) Offset the PWFS aO probe to the reference star position. Activate aO to control the primary mirror figure. (TO)

d) Position the science fold mirror in the ISS to feed light to the GMOS. (TO)

e) With the IFU *not* deployed, select the the imaging flat mirror and select a broad-band filter to restrict wavelength coverage. (O)

f) Record a short exposure of the flux standard to check that the star is located in the part of the field from which light can be fed to the IFU (in the parlance of infrared astronomers this point is often referred to as the `hot-spot' - the *approximate* location of this point would have been established when the GMOS and IFU were first placed on the telescope). Offset the telescope if necessary to adjust position of the flux standard so that it falls on the hot spot. (O + TO)

g) Deploy the IFU. (O)

h) Check the centering of the flux standard on the IF lenselet array. This is done by recording an `image' of the lenslet array, as viewed through the GMOS spectrograph. A broad band filter (preferably the one to be used to image the galaxy - see below) is selected to limit the light incident on the IFU. With the imaging flat mirror placed in the light path, an exposure *of the undispersed star light* is recorded, and a computer program which knows the spatial correspondence between the lenslets at the instrument focal plane, and the imaged location of each subaperture on the detector, constructs an `image' from the CCD output. The observer inspects the output, and determines if the star is centered on the IFU. If not, the star is moved to improve the centering. Note that this frame is saved, as it will be used for photometric calibration of images recorded of the galaxy through the lenslet array. (TO + A)

i) If it was necessary to move the telescope to improve the centering of the flux standard on the lenslet array, then it is necessary to establish the location of the new `hot spot'. To do this, retract the IFU and record another image with GMOS in wide-field mode. The location of the star on this image is noted - this is where the target galaxy will be placed when it is observed. After the new hot spot location is noted, the science fold mirror is put back into the light path.

Normally this would have been done during commissioning and checked periodically on the sky. (TO)

j) re-deploy the IFU module. (O)

k) insert into the light path the band-limiting filter to be used for the galaxy spectroscopic observations. (O)

l) select the grating required to be used for the galaxy observations. (O)

m) record spectra of the flux standard. Two different sets of exposures will be required. One will be recorded with the flux standard centered on the lenslet array, and this will be used to derive an *absolute* calibration. However, the spectral responses of the subapertures will not be uniform, and it is necessary to calibrate these differences. One method is to use a calibration white-light source and derive this information from an analysis of the spectra produced by each subaperture. If the flat-fielding of the IFU is sufficiently stable, this could be a daytime operation. However, if the white light illumination is not sufficiently uniform, another technique would be to raster-scan the star across the face of the lenslet array, so that light from the flux standard falls on each lenslet. The raster scanning could be accomplished by offsetting the peripheral guide probes, which will `drag' the telescope in the raster pattern. (O)

n) one or more velocity standards will also be observed (see below), and these data will be recorded through band-limiting filters different from those used for the galaxy observations (as the galaxies are redshifted). Consequently, a set of observations identical to those described above will also have to be obtained through the filters required for velocity calibration. (O)

o) Record an arc frame. The configuration of the spectrograph does not change. The appropriate arc in the calibration unit is turned on, and the calibration deployed. Depending on the relative strengths of the arc lines, it may be desirable to record a short exposure, with the brightest lines not saturated, and a longer exposure with the brightest lines saturated to permit use of fainter lines for wavelength calibration. It is assumed that the signal from the calibration unit will fill the entire IFU field. (O)

3. Observe Target Galaxy

Many (but by no means all) aspects of the observing procedure for the target galaxy are similar to those described in the preceding Section. Consequently, some of the following points are mentioned with little elaboration.

a) Slew telescope to galaxy location and acquire primary mirror figure reference star. Note that, unlike was the case for the flux standard, the PWFS will *not* provide the signals for guiding except during initial target acquisition - for the remainder of the observing, the positions of these probes will be slaved to the OIWFS.

b) Set up for wide field imaging. This entails (1) removal of the IFU from the light path, (2) selection of an appropriate broad-band filter for imaging, and (3) selection of the imaging flat mirror.

c) Record a 60 second exposure of the field through an *I* filter. (A reddish filter is preferred over, say, *V* as the spectral energy distributions of BCGs are very red). (TO + A)

d) Perform a quick reduction of this image using standard bias and flat-field frames. Locate the BCG on the image, compute the distance between the BCG and the hot spot, and then offset the telescope so that the target galaxy falls on the hot spot identified when the flux standard was observed. Also identify the positions of the sky subapertures on the image, and determine if a significant number of these are contaminated by stars or galaxies. Finally, if not already selected, this image could be used to select a reference star for the OIWFS. (O + TO)

e) Re-deploy the IFU. (O)

f) Position the OIWFS on the reference star, activate it and center it on the reference star. (O)

g) De-activate the PWFS guiding capabilities, and transfer these to the OIWFS. (TO)

h) Select the broad-band filter in the spectrograph that would be used for imaging through the IFU. (O)

i) With the imaging flat still in position, record a 600 second exposure through the broad-band filter. At the end of the exposure, the data acquisition computer will reconstruct an image of the BCG so that the centering of the BCG can be checked. The broad band image will be saved, as it will provide scientific photometric information. Also, check the sky levels from the sky background subapertures - is the sky level within expected levels? (O)

j) Insert filter for spectroscopic observations and select the appropriate grating. (O)

k) Record an arc spectrum. Not only will this image be used to determine wavelength calibration, but it also can be used to check that the set-up is correct before plunging into a series of long integrations. For example, are the correct grating and band-limiting filters in place? The procedure for recording an arc was described in the previous Section. However, a significant difference is that the OIWFS will not be able to access the reference star while the calibration feed optics are deployed. Consequently, guiding capabilities must be transfered back to the PWFS while the arc is in use. After the arc frame has been recorded, the calibration unit optics are retracted and the OIWFS re-activated. Note that the error signal produced by the OIWFS will automatically re-center the star on the WFS if any drift has occurred. (O)

l) Once the set-up has been checked, record three 3600 second spectroscopic exposures. At the end of each exposure check that the signal level is consistent with what is expected based on, say, the phase and angular distance from the moon. (This information would be supplied by the TCS). (O)

m) Record another arc to monitor any changes in the spectrograph due to flexure. (O)

4. Observe Radial Velocity Standard(s)
It will be necessary to observe one or more radial velocity standards to provide (1) an absolute calibration of velocity measurements, and (2) templates for comparison with the galaxy spectra as is required for, say, the Fourier Quotient method. The observing procedure for velocity standards is very similar to that described previously for flux standards, with the following differences: (1) the velocity standards are likely to be very bright, so the data would be recorded through a neutral density filter; (2) a band width limiting filter which covers the same wavelength region as the target galaxies *in the rest frame* will have to be employed - in some cases a standard broad-band filter could be used, although there will be cases where a custom filter will be required; and (3) there is no need to raster scan the star over the lenslet array.

2.3 Calibration

1. **Biases** A series of bias frames would be recorded during the afternoon immediately preceding the observations, as well as during the following morning. The bias frames recorded during each session would be median-combined to save disk space and facilitate portability.

2. **Flat-fields** Obtaining high-quality flat-field frames is of paramount importance for this science program given the low light levels of the target galaxies. Two sets of flat-field frames are required: one obtained with the grating in place, to correct the spectroscopic data, and another with the imaging flat mirror in place, to flat-field the `image' recorded through the IFU. A separate flat-field frame is required for each filter.

Both sets of flats would be recorded during the day using a continuum source located inside the calibration unit. The imaging flat-field frames are required to correct for pixel-to-pixel changes in detector sensitivity, and throughput differences between subapertures. In addition to these functions, the spectroscopic flats would also be used to correct for wavelength-dependent variations in total system response which arise due to, for example, optical coatings, etc.

2.4 Comments for Queue Observing

The preceding discussion deals with an observation of a single object, and the addition of other objects to the target list, and/or the desire to obtain these data as part of a queue-scheduled observing scheme present additional complications. For example, a more extensive survey of BCG evolution would require a sample of objects spanning a range of redshifts, so that a number of different bandwidth limiting filters would have to be available during the observing run. This problem would be further exacerbated if the IF module is used for queue-scheduled observing as a large number, encompassing all the IFU programs in the queue, will have to be readily available. One possible solution is to mount the filters in a juke box, so that they can be selected as required. The program described above also requires some interpretation on the part of the observer to select the BCG and identify sky positions, and this may not always be a straight-forward task with the information available at the telescope. Hence, to ensure success for queue scheduled observing, the investigator will have to supply high-quality finder charts.

3. Multi-Object Spectroscopy of Faint Galaxies

This scenario, which was written in conjunction with Matt Mountain, describes a possible Gemini observation to obtain spectra of a candidate cluster of galaxies at z=2, discussed by Dressler et al. *A Nascent Cluster of Galaxies at z=2?* (1993, ApJL, 404, L45). The observations would sample the 0.6 - 1.0 micron wavelength region, corresponding to restframe wavelengths 200-330nm at z=2. Observations with the HST indicate that the target objects are very compact. Hence it is anticipated that the use of a low order adaptive optics system will produce a significant improvement in the S/N of the spectra, as it will permit the use of narrow slits.

The main scientific goal of the observing program is to measure the redshifts of the objects. Consequently, it is necessary to sample a moderately long spectral region to increase the chance of making line identifications. If the objects are at z=2 then we could anticipate detecting strong absorption features, such as MgII 280.0 or OH310.0, or bright emission lines, which are seen in the spectra of star-forming systems between 2000 and 2500 Angstroms. If the galaxies are at lower redshifts, then [OII]372.7, [OIII]500.7, or Hα may be detected.

As will be seen, the success of this experiment depends largely on the quality of the seeing conditions at the time of observation. Consequently this experiment will have to scheduled as part of a flexible queuing scheme, initiated when seeing conditions reach a certain level.

An effort has been made to identify who would be responsible for the various tasks described below. `Astronomer' refers to the visiting astronomer (who could very well NOT be at the telescope, but observing remotely), while `Gemini' refers to Gemini operations personnel (e.g. the T.O., or support scientist).

3.1 Preparation

1. Derive observing parameters from galaxy modeling program. The sky background becomes very bright in the red and near-infrared portions of the spectrum. For this reason, it is important to select a slit size which maximizes light from the target galaxy, while keeping sky background to a minimum. The ideal slit width depends on a number of factors, such as seeing,

the order of adaptive correction, and the size of the target galaxy. Because galaxies are extended objects, it may not be desirable to use the highest possible order of correction if the science goal is to obtain redshifts. By using a modeling package to explore parameter space prior to observing, it will be possible to assess what is required in terms of image quality and order of correction in order to successfully complete the observing program. (ASTRONOMER)

What observing parameters will be required to observe the Dressler objects? To answer this question, a series of simulations were run using ARTDATA tasks in IRAF. An extended object with r~22 and a characteristic diameter of ~0.5 arcsec was modeled at 800nm for three orders of correction: n=1, n=5, and n=10. The S/N ratios per pixel for a spectral resolution 500 within square apertures of various sizes after a 3 hour integration were then computed using zeropoints measured from the CFHT MOS spectrograph, corrected for an 8 metre aperture. The resulting S/N ratios for 10th percentile seeing (ie. 0.25 arcsec in V) as a function of aperture width are as follows:

n	1.0 arcsec	0.5 arcsec	0.25 arcsec	0.15 arcsec
1 1	2.5	2.7	1.9	1.3
5	2.7	3.2	2.9	2.5
10	2.9	4.2	5.6	5.9

It is apparent that substantial gains in S/N ratio can be achieved by using an AO system. With a Roddier-type system (maximum n = 8), the optimum slit width is less than 0.5 arcsec. These calculations demonstrate that this is a program that can only be carried out during good seeing conditions, and hence is a good candidate for queue scheduling. The conditions required to initiate this observation are:

a) Natural seeing ~0.25 arcseconds (R_0 ~40 cm at 550nm).

b) Greenwood frequency prediction, from Radio Sonde data, within range of AO system bandwidths.

1. Order filter to define wavelength region. The output from a multi-object spectrograph is a series of spectra dispersed over the face of the detector. In order to prevent confusion, it is important that the spectra not overlap. Overlap can be minimized, and the number of observable galaxies maximized, by using filters to restrict wavelength coverage. For the current program, where broad wavelength coverage is required, it will not be possible to use standard broad-band filters, such as R and/or I. Rather, it will be necessary to order a special filter which spans the 0.6 - 1.0 micron region. (ASTRONOMER)

2. Identify reference stars. The observer should inspect the field around each cluster, and determine whether or not suitable reference stars are available. This sort of selection could be done automatically using a program supplied by Gemini; however, such a routine would have to include selected non-stellar objects, which could also serve as reference sources in a crunch. Pre-selection of reference stars will be most important for fields near the Galactic poles, and will prevent lost time at the telescope. (ASTRONOMER)

   In the particular case of the Dressler et al. objects, which are located near the northern boundary of the z=0.4 cluster 0939+4713, there are not a large number of natural reference stars from which to chose. Figure 3 of Dressler & Gunn (1992, ApJS, 78, 1) shows that there is a single brightish (r ~17-18 ?) star located in the middle of the cluster 0939+4713, some 2 arcmin from the faint objects which are the subject of the current investigation. This star is ideally suited for tip-tilt correction, and is probably bright enough for n=2 correction, although in this case the faint Dressler et al. objects would fall near the edge of the isoplanatic patch. There is an r=18 galaxy located within ~30 arcsec SW of the faint objects, but it is not clear if this would make a good reference source, due to its extended nature. For the current document, we will assume that the observations will be recorded with n=3, using the center of the bright galaxy as the reference source.

4. Identify candidates for spectroscopy. Not all the objects in a particular field will belong to the cluster being studied; rather, the field may contain a number of foreground stars, as well as foreground and background galaxies. This is especially important for the Dressler et al objects, which fall in the z=0.4 cluster 0939+4713. In order to obtain spectra of as many target objects as possible, it is necessary to identify any contaminating objects.

   Major time savings can be realized if the sample of objects for spectroscopy have been selected in advance of the observing run using, say, data recorded from other telescopes or previous Gemini observing runs. For the Dressler et al. objects the HST images could be used for this purpose. However, given the fine spatial resolutions which will be used (~0.5 arcsec slits), it will be critical that images for designing the slit masks (see below) be recorded with the same observing set-up as used to obtain spectra. This means for the Dressler objects imaging should be done using the AO system - to avoid any field distortion effects. Moreover, there may be programs where it may prove essential to use images recorded with Gemini, as the objects may be very faint.

   In the following, for the sake of generality, it is assumed that object selection will be done at the telescope on the same night as the spectra will be obtained. Until we have more experience with operational AO systems, this may be a requirement since the PSF's and isoplanatic effects are a function of the instantaneous seeing conditions. (ASTRONOMER)

3.2 Observing set up

1. The assumption is that through a combination of prediction, using Radio Sonde data, and early FWHM image measurements it is possible to initiate a set of programs that require good seeing.

2. Obtain flat-field and bias frames for image reduction. In order to design and cut the slit mask, it will be necessary to obtain deepish images of each field during the observing run, and these must be reduced in a prompt fashion, as they will be used later in the night for mask design. Consequently, calibration frames will have to be available at the start of an observing session. Bias frames and dome flats could be recorded during the afternoon prior to the nights observing. Given that more than one instrument may be used on any given night, and that it may not be possible to predict in advance when this will be, it may prove necessary to use `standard' calibration frames for each detector+instrument combination, derived from previous observing runs. (GEMINI)

3. Compute optimum conjugate layer height for the deformable mirror (DM). This step, which is crucial for maximizing the size of the isoplanatic patch, assumes that the DM can be moved in a continuous fashion along the light path so that it can focus at any arbitrary height in the atmosphere. The calculation would be done using C_n^2 profiles, obtained from a smaller side telescope, and it is further assumed that such a facility would be set up on Mauna Kea to feed this information to all telescopes using AO systems.

3.3 Imaging Set-up

1. Bring in AO system to feed MOS and set MOS to imaging. Set DM, the fast tip-tilt mirror (FTTM) and wavefront sensor (WFS) offsets for DC operation - from the system database. Position the ADC into the optical path (if appropriate), and set its prism angles.

2. Observe photometric standard star. A crude photometric calibration will be required to set the zeropoint for photometry of objects in the science field. Ideally, this would come from a standard star observed during twilight, although zero-points derived from a previous night would probably also prove acceptable. The standard would be observed using the same AO configuration as would be employed for science observations later in the evening (ie. same order of correction, etc). If very high Strehl ratios are obtained, then a set of moderately faint standards would be required, to prevent core saturation. An on-line reduction routine which provides photometric zero-points from standard star observations would be highly desirable, if not essential. Accuracy of ~0.1 magnitude is probably adequate for the task of object selection for the distant cluster spectroscopy program. This observation will also be used to check the AO gains and bandwidths. Estimates of bandwidths will have been obtained from Radio Sonde data and a atmospheric model (GEMINI).

Summary of observing sequence for standard stars

- point to standard star
- select nearby reference star
- feed reference star light to the AO WFS. It is worth noting at this point that there are at least two ways of feeding light to the AO WFS, which will be housed in the spectrograph.

  Approach A: The simplest approach is to define the reference star to be the center of the field. In this case, a moveable probe to feed light to the WFS is not required; rather, the telescope would be moved until light from the reference star falls down the central `hole' and into the WFS.

  Approach B: A more versatile (but also more prone to vignetting problems) method would be to have a moveable probe, which could pick light from a reference star anywhere over the field. In this case, the probe would be positioned in such a way that the light from the science objects fall near the center of the field.

- activate AO system using level of correction anticipated for science imaging. The AO servo-loop will automatically peak up reference star signal on the AO WFS by moving FTTM, M2, and the telescope drives.
- select filter
- record standard star images
- computer will derive photometric zero-points

3.4 Imaging of Science Field

Obtain moderately deep images of target field using standard filters. The image information will be used (1) to select objects for spectroscopy (assuming this has not already been done), and (2) to design a slit mask. Given the positioning accuracy required for narrow-slit work, and the fact that the AO system will correct optical aberrations, it is ESSENTIAL that the mask be designed from images obtained through the same light path as the spectroscopy. Moreover, in the particular case of the Dressler et al objects, multicolor imaging might be worthwhile to select candidate objects (ie. would need 2 images). Based on images recorded with the Palomar 5 metre, it is anticipated that exposure times of ~600 - 900 seconds would be sufficient in each filter for the Dressler objects. Because the data reduction, mask design, and mask cutting will take ~1 hour, images of additional program fields will be recorded while the mask for the first field is being prepared. (ASTRONOMER)

Summary of observing sequence for imaging:

- acquire reference star
- turn on AO
- select filter
- obtain short (~60 second) exposure to check field (ie. make sure that key objects are not located on bad pixels, or just off the field) and monitor image quality. The success of many of the projects to be done with Gemini will hinge on the image quality. If conditions are poor, then AO will give only modest gains, and it may be more profitable to pursue programs which require less stringent atmospheric conditions. The short exposure recorded in this step would be used to check that the AO system is producing the predicted gains.
- record deep exposure for each filter

System Monitoring - DM and WFS sensor offsets will have to be monitored, and automatic FWHM and Strehl ratio measurements compared with expected values. If wind conditions begin to degrade, DM and tip/tilt amplitudes may become too extreme and a re-optimization of the enclosure may be required. If Strehl ratios begin to degrade bandwidths may have to be re-optimized

3.5 Mask Construction

1. Reduce imaging data. Ideally, this would be done automatically while observations are being recorded. (GEMINI). Reduction sequence for imaging data:
    - subtraction of bias frame
    - division by dome flat appropriate for filter
    - visual check of results (are the data flat?, etc)
2. Select objects. This would be done with a program, supported by Gemini, that does star/galaxy separation, and can perform photometry of extended objects; examples of such software are FOCAS and PPP. When used with AO data, it will be essential for the

software to account for PSF variations across the field (due to non-isoplanicity). The photometry routine should also assign priorities to objects based on properties such as colour, brightness, etc, as it may not be possible to obtain spectra of all objects (see step 3). The program should also select a small number of moderately bright reference sources, which would be used to align the instrument environment with the slit mask prior to observing, and serve as flux calibration sources. In the Dressler et al. field, galaxy 460 from the study of Dressler & Gunn (1992) could be used as such a reference source. (ASTRONOMER)

3. Design slit mask. Once a sample of objects is selected, the information can be used to compute the locations of slits on the mask. This will be an iterative process in crowded fields, as overlap of spectra may prevent obtaining spectra of two objects which are very close together on the sky. Moreover, the software must also determine if objects can be located in the middles of slits, or at slit edges. Because of isoplanicity effects, the program may also select slit widths to vary with distance from the reference star. In the case of the Dressler et al. program, 0.5 arcsec slits would be used. Finally, the program would organize the slits in a manner which would be most efficient for cutting of the mask.

If the data is to be flux calibrated, then it will be necessary to cut a second mask, with very broad slits centered on brightish point sources (which could be the sources used to align the mask - see point 7.2 below). Why is it necessary to obtain spectra through wide slits of objects in the science field? This is necessary as the level of compensation delivered by the AO system varies with wavelength, time, and location in the field. By comparing the wide slit spectra of the bright on-field sources with spectra of the same objects recorded through the narrow slits used for the science observations, it will be possible to define the wavelength and spatial dependencies of the aperture correction on the frame. In the case of observing the Dressler et al. objects, flux calibration is highly desirable, as the shape of the spectral-energy distribution may prove useful for secondary redshift identification and/or for determining the nature of the objects. (ASTRONOMER)

Summary of slit mask design

- run galaxy photometry package on reduced broad-band images
- using criteria such as brightness, colour, and size, select objects which are to be spectroscopic targets
- assign priorities to objects
- feed target list to mask design software which produces a template for the slit mask which contains as many target objects as possible, weighted according to

priorities assigned in the previous step. The software would check to prevent spectral overlap

- send results of design program to the mask cutting machine

4. Cut the mask. Once the mask is designed, a laser cutting machine would be activated to cut the mask. The use of a laser, as opposed to a mechanical cutting routine, is preferred given the narrow slit widths that will be used. (GEMINI)

5. Place mask in spectrograph. The slit mask would be cleaned (to remove ratty edges), and then physically mounted in the spectrograph (presumably in a cassette which would accommodate a large number of slit masks). If the data are to be flux calibrated, then the mask cut with wide slits for the brightest objects should also be installed in the spectrograph (GEMINI)

3.6 Spectroscopy

1. Point to science field, and reacquire reference star. If the light from the reference star is intercepted by a moveable probe, the probe would be moved to the same position as was used for imaging. The position of the probe may have to be altered slightly once the slit has been aligned on the sky, which is discussed in the next step. (GEMINI)

2. Align mask on the sky. While the slit was being designed and cut, the telescope was being used to observe other fields. To reacquire the cluster field, it will be necessary to rotate the instrument environment to align the slit mask on the target objects, using reference stars selected during mask design (step 2 above). (GEMINI)

3. Insert cluster filter in light path. (GEMINI)

4. Insert dispersing element in light path. (GEMINI)

5. Activate AO system, and take short arc exposure. An arc exposure would be recorded to check wavelength centering. Moreover, for spectroscopic studies of faint sources, exposure times of 1 - 3 hours may be required, so it would be desirable to bracket science frames with wavelength calibration information to assess and compensate for instrument flexure. If the calibration arc is part of the ISS calibration unit, then the folding mirror which feeds sky light to the AO system must be repositioned to permit light from the calibration unit to be fed to the spectrograph through the AO system. As this requires a mechanical repositioning of the folding mirror, it is critical that the wavelength calibration be done before set-up of objects on the slit mask, otherwise a misalignment between the target objects and their slits may occur (step 7.6). (ASTRONOMER)

6. Remove dispersing element from the light path, and take short exposure to adjust positions of objects on the slit mask. A short exposure would be recorded through the slit mask (without the dispersing element!) to check that bright objects in the field (e.g. the reference objects - e.g. galaxy 460) are located in the middle of their slits. If not, the instrument environment would be rotated, or the telescope moved by electronically or mechanically offsetting the AO WFS, which drags the M2 and then the telescope. Ideally, the short range offset accuracy should be ~0.01 arcsec over sub-arcsec throws, otherwise it will be necessary to take another exposure, and re-check object centering. In order to save CCD read time, it may be desirable to inspect sub-rasters centered on the alignment reference sources. The light profiles of the reference stars would also be inspected to check that the image quality has not degraded since the broad-band images were taken. (ASTRONOMER)

7. Insert dispersing element in the light path and take spectra of science objects. If skipper amplifiers are available, it will be possible to monitor the progress of the data acquisition, and make sure that the objects stay within their respective slits. This may prove critical for studying high-z clusters, where 3 hour exposures will be required to obtain spectra of fainter cluster members. (ASTRONOMER)

8. Take short arc exposure. (ASTRONOMER)

9. Take continuum lamp exposure. With the dispersing element in place, a short calibration exposure is recorded in which a continuum source is fed through the spectrograph. This frame will be used to remove pixel-to-pixel variations from the spectra, and compensate for slit illumination effects (the slit edges will contain some jagged features, and there may be vignetting). The latter step will be essential for faint object spectroscopy, such as studies of high-z clusters in the red/near-infrared, where the signal from the source will be dwarfed by bright sky lines. (ASTRONOMER)

10. Rotate mask holder so that the flux calibration mask is in place. Check mask alignment with the sources as above and, with AO system operating, record spectra of on-field flux stars.

Summary of spectroscopy for faint sources:

- Point to field, and reacquire reference star

- Rotate instrument environment to the angle used to record the broad-band images from which the slit mask was designed

- Rotate slit-mask wheel to put mask in the line of sight

- Rotate filter wheel to put filter for cluster in light path
- Activate AO system
- Insert dispersing element in light path
- Position AO feed mirror for calibration work; turn on calibration arc, and take short exposure
- Turn off calibration arc
- Reposition AO feed mirror for sky observations. With dispersing element not along the light path, record a short broad-band image through the slit mask
- Check if bright objects are correctly located; if not, either rotate instrument environment, or move telescope to compensate. Also check image quality
- Start long spectroscopic exposure of target cluster, periodically monitoring output from detector
- After end of cluster observations, take another arc exposure
- Turn off arc, and turn on continuum source
- Take exposure of continuum source spectrum
- Record spectra of bright on-field sources which will serve as secondary flux standards.

3.7 Observe Flux Standard

For most applications (e.g. measuring the strength of the 4000A break) it will be desirable to flux calibrate the spectra. Consequently, a flux standard would be observed using, for example, a long-slit mask mounted (permanently?) in the slit mask cassette. The flux standard would be observed using the same observing configuration as the faint galaxies (ie. same filter, order of AO correction, etc). (ASTRONOMER)

Summary of flux standard observations

- Point to flux standard and find reference star
- Rotate mask filter wheel so that wide, long-slit mask is in the beam

- Rotate filter wheel to put filter to be calibrated in the light path
- Activate AO
- Insert dispersing element
- Position AO feed mirror in ISS for calibration work. Turn on comparison arc, and record arc spectrum
- Turn off arc lamp
- Position AO feed mirror for sky observations. With dispersing element out of light path, take a short exposure to see that the flux standard is centered in the slit - if not move telescope as required
- Take spectrum of flux standard
- Turn on continuum lamp, and record continuum spectrum

3.8 Facility Requirements

It is anticipated that Gemini will provide the following capabilities to aid astronomers in obtaining multi-object spectroscopy:

1. An on-line guide star catalogue - required to pre-select fields to be observed.
2. A galaxy modelling package, to help astronomers determine the best observing configurations for their observations
3. On-line image processing - required for mask design.
4. Galaxy photometry software - required for mask design. Note that this software must allow for variation in PSF across image.
5. Mask design software - required to pack as many slits as possible, without spectra overlap, onto the slit mask.
6. People - if the astronomer does not travel to Mauna Kea, it is apparent from the observing procedure described above that at least two people will be required at the summit - one to operate the telescope, the other to operate the slit cutting machine. These requirements

could be relaxed somewhat if slit masks are cut during the day, from images recorded on the previous night.